SQUAMISH ESTUARY MANAGEMENT PLAN

Air and Water Quality Work Group Final Report

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To these people, we express our thanks.

I Introduction

1. INTRODUCTION

1.1 History of Study

The Squamish Estuary Management Plan was initiated in May, 1979, by the Federal and Provincial Governments to develop a management plan for the Lower Squamish River and estuary.

The study examined concerns related to land use, recreation, habitat for fish and wildlife, and air and water quality. Four technical work groups directed by a Federal-Provincial Planning Committee, were organized to report on these subjects.

1.2 Study Boundaries

The area under study is the Squamish River downstream from the Mamquam River, as well as the estuary area to the five fathom contour at the estuary delta front.

1.3 Objectives of the Air and Water Quality Work Group

The main objectives outlined in the terms of reference for the Air and Water Quality Work Group were as follows:

- To describe from existing literature, unpublished data, and general knowledge, the air and water quality of the Squamish Estuary
- To investigate and recommend ways to maintain and enhance water quality
- To identify existing or potential conflicts in water use
- To recommend an on-going monitoring program for ambient air, air emissions, effluent discharges and receiving waters
- To identify major gaps in data and understanding

II Meteorology

2. METEOROLOGY

2.1 General

Information on the general meteorological conditions in the Squamish River Estuary area have been summarized by Hoos and Vold (1975) and by Coligado and Wilson (1979).

Usually, the estuary experiences a maritime climate although wind and temperature regimes tend to be accentuated compared to coastal areas, since Squamish is further inland, at the head of Howe Sound. A summary of the main meteorological parameters is given below.

2.2 Temperature

Figure 1 shows the mean monthly temperature recorded for Squamish and Britannia Beach, based on Atmospheric Environment Service records, 1941-1970. Squamish is slightly cooler than Britannia because it is influenced more by the cold air movement from the Squamish Valley. In addition, the Squamish weather station is closer to sea level (+2 m) than the one at Britannia (+49 m) and thus is affected more by the waters of Howe Sound, which in general are cooler than the surrounding land mass. At Squamish, highest temperatures (16-18^{o}C) occur during June and July, while December and January are generally the coolest months (1-2^{o}C).

2.3 Precipitation

Figure 2 shows the mean monthly precipitation (mm) for Squamish, Britannia Beach and Woodfibre (Atmospheric Environment data records, 1941-1970). In general, Woodfibre has the highest precipitation levels and Squamish the lowest. The difference is about 15 to 20 mm during the summer but exceeds 150 mm during the winter months.

October to April are the months of greatest precipitation in Squamish, ranging from 150 to over 300 mm. May through to August are the driest months,

averaging between 50 and 100 mm precipitation. The mean annual precipitation is over 2 000 mm, including an annual mean snowfall of nearly 1 500 mm. The estuary averages about 155 days with measurable rainfall and 14 days with snowfall (Hoos and Vold, 1975).

In the Howe Sound area, 50 to 60 percent of the days between October and April experience measurable precipitation, while rain occurs only 30 to 35 percent of the days from May through September (Coligado and Wilson, 1979). A summary of temperature and precipitation information, 1941 to 1970, from the Atmospheric Environment Service has been published in Hoos and Vold (1975).

2.4 Winds

Winds at Squamish prevail from the north in the fall, winter and early spring, and from the south and southwest during warmer months. Northerly winds are predominantly the result of the drainage of cold air down the river valley plus outbreaks of arctic air from the interior. In the summer there is a marked diurnal land/sea breeze cycle, caused by the temperature differential between the land and water surfaces. From midnight to late morning the winds are from the land, reversing during the afternoon and evening.

The funneling effects of Howe Sound result in wind speeds from the south of 30 to 50 kilometres per hour (km/h). The arctic outbreaks from the north, which occur on average 5 or 6 days a month in winter, can result in winds averaging 55 to 65 km/h, with gusts of over 100 km/h.

While north winds predominate on an annual basis, the highest average speeds are associated with the southwest winds (Figure 3). The mean annual speed is 15 km/h. Calm days occur on an average of 9 percent of the time from May to September, and an average of 4 percent of the time the rest of the year (Coligado and Wilson, 1979).

Table 66 indicates the diurnal variation in wind direction at the Langdale ferry terminal during the three months for which data were analyzed. Over seventy-five percent of the winds were from the west between the hours of 20:00 and 06:00. The majority of these winds probably result from drainage

off the hills to the west of Langdale. These winds were light, averaging 5.9 km/h in August, 5.1 km/h in September, and 5.2 km/h in October.

Between the hours of 11:00 and 15:00, over fifty percent of the winds were from the south. This appears to be a valley wind up Howe Sound. Speeds averaged 11.7 km/h in August, 11.0 km/h in September, and 8.3 km/h in October. North and northwest winds occurred about ten percent of the time. North winds occurred mostly in the daytime while northwest winds occurred at night. Speeds ranged between 5 and 6 km/h. The average speed for all wind directions was 7.7 km/h in August, 6.2 km/h in September, and 5.8 km/h in October.

The situation with west winds at night at Langdale could cause problems for atmospheric dispersion. A surface-based inversion likely accompanies the cold air drainage trapping pollutants emitted below the top of the inversion. Limited horizontal mixing would occur due to the light wind speeds. When the inversion breaks up with daytime heating of the lower layer of the atmosphere, high concentrations of pollutants may occur due to fumigation. Fumigation is the phenomenon in which pollutants that had remained aloft in stratified stable air are brought rapidly to ground level when the air is destabilized. Fumigation has already been identified as a local problem at the Woodfibre pulp mill (Rayonier Canada Ltd., internal report).

The Air Studies Branch of the Ministry of Environment will continue to measure wind speed and direction at Langdale until at least August 1981. Additional measurements of surface winds will be required if other industrial developments take place in Howe Sound.

2.5 Atmospheric Stability

There are few data available on the vertical temperature structure in the Squamish area. However, some preliminary predictions, based on a knowledge of atmospheric processes, have been made. "During sea breeze episodes the cold surface air from Howe Sound would produce an inversion, but strong winds produce good horizontal dispersion. In winter the periods of strong outfalls of cold air to the relatively warm sea would produce good vertical mixing. Southerly winds in winter would produce inversion conditions as the milder marine air lifts over the colder residual air of the valley. The seasonal percentage frequency

of ground-based inversions at Squamish at two times of the day (mid-afternoon and early morning) would be approximately as shown in the following table:

	Winter	Spring	Summer	Fall
PM	20%	15%	35%	25%
AM	45%	55%	75%	70%

Thus inversions would be most frequent in summer, but the mixing depth would be considerable" (S. Nikleva, personal communication).

During two five-day periods measurements of upper level winds and temperatures were made. These periods were from August 18 to 22 and November 24 to 28, 1980. The balloons and transmitters used to make the measurements were released from Squamish Terminals. The purpose of making these measurements was to determine atmospheric stability conditions and the upper level winds that affect pollutants as they rise. The study could not cover all atmospheric situations since only two seasons were monitored.

Conditions were similar each day during the August period. In the mornings, atmospheric conditions were stable and winds were light, predominantly from the north. In the afternoons, conditions were neutral to unstable, and surface winds very strong from the south extending to about 500 metres above ground. When the winds shifted from north to south, fumigation occurred. There were no measurements of ambient air quality but the emission of reduced sulphur compounds from the Woodfibre mill could be smelled until the wind speeds increased and the unstable layer deepened.

In November, there were few examples of a change in wind direction during the day. Most of the time, low level winds were from the north, while above 500 to 1 000 metre winds were from the south or southwest. Figure 46 indicates on a plan view an example of this, indicating the position of the balloon every thirty seconds during its ascent. Atmospheric conditions were mainly neutral to unstable with a number of frontal passages and accompanying showers.

Figure 47 indicates the vertical temperature profile during three

balloon ascents on November 25, 1980. The dry adiabatic lapse rate is shown for comparison. Lapse rates greater than dry adiabatic are associated with unstable conditions, during which there is good vertical mixing of pollutants.

The conditions observed during August and November indicate that an intensive study of atmospheric conditions in the Squamish area should be undertaken prior to the construction of a major air emission source. Air flow in the area is complex, and stability conditions that can result in fumigations occurring quite frequently.

III Hydrology

3. HYDROLOGY

The Squamish River Basin lies in the Cordillera physiographic region which is predominantly mountainous with underlying crystalline and folded sedimentary rock (Zrymiak and Durette, 1979). The basin has a drainage area of approximately 2 670 square kilometres through which the Squamish River meanders for about 45 km to the Squamish Estuary and Howe Sound. The main tributaries of the Squamish River are the Elaho, Cheakamus and Mamquam Rivers. The Mamquam River has not always been a tributary of the Squamish River. Before 1921 it flowed into the present Mamquam Blind Channel forming the Mamquam estuary, but a major flood and some flood control measures in the early 1920's re-directed the flow to the Squamish River (Stathers, MS, 1958 from Levings, 1976). Another flood in 1945 cut a new channel through the delta (Giovando, 1972). The present flood control facilities (Section 3.1) restrict the flow of the Mamquam River to the Squamish River.

Figure 4 shows the mean monthly flows for 1966 through 1978 (Inland Waters Directorate, 1977, 1978, 1979) for the Squamish River, the Cheakamus River near Brackendale (site 08GA043), and the Mamquam River near Brackendale (site 08GA054). The site locations are shown in Figure 5. The hydrograph for the Squamish River was obtained by combining corresponding data for the Squamish River site 08GA022 near Brackendale and the Mamquam River site 08GA054. This hydrograph approximates the flow of the Squamish River downstream from the Mamquam River confluence, or the flow to the Squamish Estuary (i.e., the study area).

Data for the third main tributary, the Elaho River, are only available for 1955 to 1957 and are not included in Figure 4. For the three year period the mean monthly flows ranged from 8.5 cubic metres per second (m^3/s) in February to 190 m^3/s in July. The ranges of mean monthly flows for the Cheakamus and Mamquam Rivers (Figure 4) were less extreme, 15.7 to 88.5 m^3/s and 15.6 to 55.5 m^3/s, respectively, perhaps due to greater sub-surface water input.

In addition to the mean monthly flows given in Figure 4, the minimum and maximum mean monthly flows for the Squamish River downstream from the Mamquam River confluence which occurred between 1966 and 1978, inclusive, are

shown. The annual flow pattern is typical of a mountain fed river with low mean monthly values in the December through March period (104 to 128 m^3/s) and high values following mountain ice melt in the May through August period (348 to 570 m^3/s). The minimum and maximum mean monthly flows were 38 m^3/s in December, 1978 and 815 m^3/s in June 1967. However, high daily discharges which resulted from increased precipitation in combination with a sudden snow melt are a common feature of the Squamish River, particularily in late fall. This is reflected in the slightly skewed hydrograph and in flow records, which show that maximum daily discharges for the period from 1966 through 1978, occurred during October, November or December in six of the 13 years. When this occurs in concert with high winds and high tides, flooding of the Squamish delta can result (Hoos and Vold, 1975). Flood protection facilities are discussed in Section 3.1.

The Stawamus River is not within the Squamish River Basin but flows into Mamquam Blind Channel which is in the study area (Figure 6). The Stawamus River is the principal source of domestic water for the District of Squamish (Section 3.2). The mean monthly flows recorded for the period 1972 and 1978 for the Stawamus River below Ray Creek (site 08GA064) range from 1.25 to 7.9 m^3/s (Inland Waters Directorate, 1977, 1978, 1979).

3.1 Flood Protection and River Training

The locations of the existing dykes and floodgates constructed in the early 1970's, and those proposed for the Squamish area are shown in Figure 7. The dykes were designed to protect the area against a one in fifty-year flood (i.e., to withstand the water levels which occur, on average, once every fifty years), but subsequent analyses of the peak flows of the Squamish River indicate that the dykes provide protection against a one in two hundred-year flood. This represents an estimated discharge rate for the Squamish River, at Squamish of 3 880 m^3/d, with an instantaneous peak of 4 650 m^3/d (McNeil, personal communication, cited as McNeil, 1974).

A dam forming Daisy Lake on the Cheakamus River, built in 1957 for hydro generation, has also provided some flood protection. However, the impact of the dam is not great, since the Cheakamus River contributes only about 13 percent of the flow to the Squamish River.

Improvements to the flood control facilities have been proposed (Wester, personal communication). These include a continuation of the dyke southward along the upper section of the Squamish River from the rock quarry inflow to the Mamquam River confluence, then along the northern bank of the Mamquam River to the golf course, and improvement to the fill and rip rap on the existing dyke along the Mamquam River. Implementation of these proposals depends on further analyses of need, habitat alteration, residential development proposals and funding.

Flooding which occurred in December 1980 did not result from failure of the existing dyke system. No physical evidence existed to indicate that flooding in the Judd Slough area was related to overtopping of dykes, but resulted from water that backed up along a creek (McFadden, personal communication).

In addition to providing flood control, the dyke along the southern portion of the Squamish River (Figure 7) was designed to train the river to the west side of the estuary, and to prevent fanning of the delta to the east. Such fanning would interfere with the port facilities and proposed harbour (Section 5.3.1). The prevention of such fanning is the main function of the section of the dyke which extends seaward to Howe Sound. Dredging of the Squamish River to increase the river capacity downstream from the Mamquam River was carried out in conjunction with the dyke construction in the early 1970's.

Several studies have examined changes in the water and sediment characteristics of the Squamish River and the inner estuary following dredging and construction of the dykes. In 1973, 1974 and 1978, surveys were conducted to monitor the sedimentation process in the Squamish River from the delta to a point about 1 km downstream from the Mamquam River confluence (Zrymiak and Durette, 1979). The results were discussed for the upper (2.27 to 3.42 km from the delta), middle (0.4 to 2.27 km from the delta) and lower (delta to 0.4 km) estuary sections of the river. In the upper estuary section, there was a net degradation of the substrate resulting from increased river velocities and erosion due to the river training. However, the upper estuary section is now considered to be stable.

A steady state of aggradation of sediment in the middle estuary gave an increase in mean river bottom elevation and a decrease in average downstream

slope. This was attributed to natural forces returning the channel to regime conditions following alterations caused by dredging and dyking. It was also attributed to the maximum daily discharges during the survey period being of a normal order of magnitude. Thus, no excessive scouring occurred as would have occurred during abnormally high discharges. There is still aggradation along the northwest bank due to erosion, which is causing the river bend to migrate downstream. This in turn forces the river flows diagonally across the channel and causes some erosion along the dyke. Otherwise, the middle estuary section is stable.

In the lower estuary section, there was a net aggradation of sediment with indications that the delta is advancing at a steady state. Sediment deposition is occurring both along the delta face and at the front of the dyke. The latter was attributed to the diagonal river flow and dyke erosion occurring, just upstream, in the middle section.

Zrymiak and Durette (1979) recommended continued monitoring of the sediment processes, particularily in the vicinity of the migrating river bend and the delta. This should be encouraged, as the data to date suggest that the delta may extend towards the proposed harbour.

Changes in the water chemistry of the estuary due to construction of the dyke are discussed by Pomeroy and Stockner (1976) and Levings (1980). The changes are reflected in salinity, temperature and to a lesser extent dissolved oxygen values, which are summarized in Chapter 9. In general, there has been almost complete elimination of the riverine water flow to the east area (also referred to as the central basin) resulting in a change from a brackish to a more marine condition. Fresh water input has been reduced to that flowing through two culverts which have a maximum flow capacity of 1.5 m^3/s (Bell, 1975). The associated changes in habitat are discussed in the Habitat Work Group Report (1980).

The dykes have affected Mamquam Blind Channel by eliminating the possible return of the Mamquam River to its pre-1921 route.

3.2 Water Use

The use of surface waters requires a water licence from the Water Management Branch of the B.C. Ministry of the Environment. Water licences which have been issued for the Squamish area are summarized in Table 1. The major sources of water are the Stawamus River and tidal channels.

The Stawamus River is the principal source of domestic water for the District of Squamish. Squamish Water Works is permitted to withdraw 11 365 m^3/d from the river. The water is taken from a small reservoir created by a weir on the river.

Squamish Water Works used an estimated 2 800 000 m^3 of water during 1979, for an average usage of about 7 700 m^3/d. This represents about 1 to 5% of the mean monthly flows of the Stawamus River for 1972 to 1978, inclusive (158 000 to 624 000 m^3/d). However, it is about 15% of the minimum mean monthly flow recorded in February, 1975 (52 500 m^3/d). To accomodate low river flow periods, the District of Squamish has a conditional water licence (licence 25775) allowing the use of 680 m^3/d from Mashiter Creek. The usage of water from this source has not been required, to date.

Three of the industries in the Squamish Estuary utilize water for cooling, in their processes. F.M.C. of Canada Ltd. withdraws 33 000 m^3/d, while Hooker Chemicals Ltd. withdrew 6 800 m^3/d of saline water from the estuary until early 1980. At that time, Hooker installed a closed circuit cooling system, which utilizes make-up water from the District of Squamish. Weldwood of Canada Ltd. uses approximately 390 m^3/d of water from the District of Squamish system.

A number of small water licences have been issued for several creeks between the Mamquam River and Brackendale, as well as on the Mamquam River itself. Details of these licences are outlined in Table 1. The total quantity of water involved is small, averaging less than 1 500 m^3/d during the May through September irrigation season, and less than 100 m^3/d during the remainder of the year.

The supply of water for the Squamish area does not appear to constitute a problem at present. However, the availability of water may warrant consider-

ation if new developments require extensive quantities of fresh water, since neither the Squamish nor the Mamquam Rivers are generally suitable for drinking water or many industrial uses without pre-treatment (see Chapter 8).

IV Estuarine Circulation

4. ESTUARINE CIRCULATION

The Squamish River and the inner portion of Howe Sound represent a classic fjord-estuarine system in that there is a major freshwater input at the head of a long, narrow and deep channel. In such a system, the freshwater from the river moves into the channel, spreading out as a thin layer overriding the denser seawater below. Some upward mixing occurs at the freshwater-seawater interface, salt water thus becoming entrained into the freshwater is carried seaward. There is a strong pycnocline (rapid density increase with depth) generated essentially by salinity, between the less dense fresh or brackish surface layer and the underlying high salinity water. Saltwater so removed must be balanced by a compensating inflow at depth.

This estuarine circulation, essentially seaward at the surface and landward at depth, can be influenced by such factors as wind and tide. A further feature affecting the circulation in this system is the sill, 70 metres deep, located at the end of the channel, between Defense Island and Porteau Cove (Figure 9). The basin, bounded longitudinally by this sill and the head of the Sound, has a maximum depth of about 300 metres. The sill acts as a barrier to the free and continuous exchange of water between the basin and corresponding depths to seaward.

Deep basin water (below 70 metres) can only be renewed when the density is less than that of inflowing water attaining the sill. This exchange can be either partial or total. Between exchanges, circulation and properties of the basin waters appear to be functions primarily of diffusive processes. Long residence times of deep basin waters can result in a reduction of dissolved oxygen (Section 9.1.3) which in turn can have serious biological implications.

At the head of the fjord, the relatively dense saltwater can intrude into the river at depth as a wedge. The distance that the wedge penetrates upstream is influenced by river flow, tide, and the topography of the delta.

Several studies on the circulation and properties of inner Howe Sound waters have been carried out within the past decade (Giovando, 1972; Bell, 1973; Buckley and Pond, 1976; Buchanan and Stockner, 1976; Levings et al., 1976; and Levings, 1980).

The primary study of the general surface circulation within the channel was carried out by Buckley and Pond (1976). Free-floating drogues were tracked by radar for several days. Figure 10 indicates this circulation, with wind effects averaged out. The authors demonstrated that wind forcing was the dominant factor in the circulation and that the large daily variation encountered in the wind velocity caused a surface-current variability an order of magnitude larger than the expected flows due to river discharge and tides. The river output caused large horizontal shears in the flow, especially 15 kilometres downstream from the head. Tidal effects appeared to be minimal. The surface layer (a few metres deep) is only very weakly coupled to the water below. The layer tends to absorb all the effect of the wind, and move much like a "slab" independent of the underlying waters.

Giovando (1972) examined the surface circulation at three locations off the front of the Squamish River delta. He suggested that any significant net flow, particularly during strong river runoff, was confined to the uppermost few metres, and to the area immediately off the mouth of the river. To a depth of two metres, currents off the river mouth attained values of approximately 22 km/day. Surface-current values at the other sampling sites, as well as those at ten metre depths, were very much less than the speeds at the river-mouth. The training dyke bounding the eastern side of the river was thought to be responsible for the large differences in surface flow with location. A counter-clockwise surface flow across the delta front in the vicinity of Mamquam Blind Channel was also suggested.

Information on the water circulation patterns at depth in the basin is contained in Bell (1973). His conclusions are based largely on salinity and dissolved oxygen data, which are discussed in Sections 9.1.1 and 9.1.3. He showed that the water inward from the sill, to intermediate depths, was frequently renewed. However, complete renewal occurred only every three or four years. The triggering mechanism for the renewal process was associated with a strong down-inlet flow of surface waters which would result in an increased bottom inflow of relatively dense seawater across the outside sill. The extent of the increased surface flow determines the extent of the seawater inflow over the sill, and thus the extent of water renewal. Strong down-inlet winds

and large river flows were suggested as the principal causes of the increased surface flow.

Using the data from Bell (1973) for a station north of the sill, Buchanan and Stockner (1976) reported a net down-inlet flow averaging 5 km/d at depths of three and five metres. Maximum down-inlet flow occurred in summer but high current speeds were found in winter as well. There was no correlation between the maximum current speeds and peak river discharge rates, suggesting that the wind was the dominant factor. This agrees with the conclusion reached by Buckley and Pond (1976). At a depth of 10 metres the current direction is reversed 180^{o}. The authors indicated that this depth may be the transition zone from down-inlet to up-inlet water flow.

Several studies on circulation in the inner delta area, including the river mouth, are available (Hoos and Vold, 1975; Pomeroy and Stockner, 1976; Levings, 1976; and Levings, 1980). These studies were designed primarily to investigate changes in the inner estuary associated with construction of the river training dyke, which has reduced freshwater input to the central basin and brought about a change towards a marine regime (Section 3.1). There is some freshwater input near the culverts (Figure 11, Levings, 1980). The salt wedge penetration appeared to be dependent largely on the river discharge. At low river flows (200 m^3/s), Levings (1980) found the salt wedge to reach to the vicinity of the culverts (Figure 11), about 1.5 km from the river mouth. During high river flows (500 m^3/s) the wedge did not move past the river mouth (Levings, 1980). These results are based largely on salinity, temperature and dissolved oxygen measurements which are discussed in more detail in Chapter 9.

V Air Emissions, Liquid Effluents, and Solid Wastes

5. AIR EMISSIONS, LIQUID EFFLUENTS, AND SOLID WASTES

Generally, operations in British Columbia which discharge air emissions, liquid effluents, or solid wastes are required to obtain and comply with conditions of a pollution control permit. These permits are issued under the authority of the Director of Pollution Control, who administers the Pollution Control Act. The permits contain limits on discharge rates, contaminant concentrations, and monitoring requirements. These limits and requirements are based upon provincial objectives which were issued as a result of public enquiries.

5.1 Forest Industries

Revised Pollution Control Objectives for the Forest Products Industry of British Columbia were issued by the Pollution Control Board in 1977. The Objectives relate to discharges to air, water, and land. Objectives described as "A" level are desirable goals for all discharges, and generally apply to all new discharges. Objectives described as "B" level are intended as acceptable interim objectives for all other discharges.

The Interim Report of the Land Use Work Group dealt extensively with log handling in the Squamish area. This information will not be reproduced here; however, the effect of log handling in water, with subsequent bark deposition, should be noted as a contributing cause to dissolved oxygen depressions in the water at certain locations.

5.1.1 Weldwood of Canada Ltd., Empire Lumber Division

(a) Plant Operation

This sawmill-planemill complex is situated on the east bank of Mamquam Channel and has been operational since 1962 (see Figure 12). The mill produced 540,000 board feet (fbm) per day of hemlock dimensional lumber and timbers for local, as well as export markets, during 1978.

A simplied flow diagram for the plant operation is shown in Figure 13. Logs are trucked to, and sorted on, the west bank of the Mamquam Blind Channel,

prior to being boomed. The hemlock logs enter the mill by two pond chains. Larger diameter logs are sent into the head rig sawmill line, while smaller diameter logs are sent to the quad sawmill line.

In the mill, the logs are mechanically debarked, and sawed into appropriate sizes. The hogged materials, from the mechanical debarkers, are sold to various industries such as Reichhold who convert the bark which is used off-site as a glue additive, or for use in power boilers. The logs are then edged. Some of the edged logs from the head rig line are sold directly for resawing, while the remaining squared logs are cut into dimensional lumber and are planed. Prior to 1970, excess or non-saleable wastes were disposed of in a beehive burner located on the property. Since 1970, unsuitable woodslabs from the edger, or other wastes from the planer mill, have been passed into chippers. The sawdust and wood chips which are produced are separated in cyclones, and are loaded onto barges for shipment to pulpmills.

The finished lumber is graded and dried, with some of the lumber being preserved with a solution in a dip tank. The dip tank is a potential source of polychlorinated phenolic compounds, and is discussed further in Chapters 10 and 11. The tank is located near the bank of Mamquam Blind Channel. Its close proximity to the bank leaves no area available for containment in the event of loss of wood preservative solution.

Compressed air is used in the mill to power equipment that requires simple low control movement, such as dogging or lumber flipping. Three compressors are in use at the mill, one installed in 1962 and rated at 300 horsepower (Hp), and two installed in 1973 and rated at 150 Hp each. Indirect cooling water (390 m^3/d) is employed in all three compressors (Table 1). The cooling water is discharged directly through two outfalls into the Mamquam Blind Channel.

(b) Air Emissions

Air emissions originate from plant cyclones, and are covered by pollution control permit PA 2061. A summary of the permit limits and conditions for monitoring, are included in Table 2. No monitoring data are available for this emission.

(c) Liquid Effluents

Liquid effluents originate as indirect compressor cooling water at this operation. The maximum values for flow and temperature allowed by pollution control permit PE 4951, as well as a summary of the monitoring data, are included in Table 2. The available data, from only one sample, indicate that the maximum permit limit for temperature of 35°C, as well as other parameter values listed in the Objectives, were met.

Analytical results for trace organic contaminants of a sample of yard drainge collected in November 1980, are discussed in Section 5.7.2

(d) Solid Wastes and Other Non-Point Sources

Solid waste from the dry land sorting facility is disposed of on a 0.6 hectare site below the powerlines north of the Mamquam Blind Channel. The site is bordered on the east by rock cliffs, and on the north and west with berms of impervious material. (The permeability of the berms was not tested in this study). The most northerly portion of the site is traversed by a creek, which then runs southerly for approximately 300 metres before flowing westwardly. Limited monitoring of this watercourse by the Waste Management Branch has shown only minor evidence of contamination from the site.

An inspection of the area in September 1980 revealed that wood waste and a mid-depth earthen layer was piled to an estimated 3.5 metre depth. The surface of the site appeared relatively level, with little final cover material present on an estimated one-third of the surface area.

A sample collected from a culvert draining the southern portion of the area in June 1980, during a period of low precipitation, indicated a concentration of phenolics of 0.005 mg/L, a tannin and lignin concentration of 60 mg/L, and a total organic carbon concentration of 3 mg/L. These values were higher than were recorded during the same time period for other discharges entering Mamquam Blind Channel.

The spillage of wood chips during the loading of barges in the Mamquam

Blind Channel was observed during the summer of 1980 during work sponsored by the Air and Water Quality Work Group. Although the spillages were of relatively minor quantities, the cumulative effect was evident in large quantities of chips in the sediments of Mamquam Blind Channel, adjacent to the loading facility.

(e) Recommendations

The operation should monitor air emissions and liquid effluent discharges as required by the relevant pollution control permits. The Waste Management Branch should continue to monitor the watercourse adjacent to the site. The company should investigate methods of reducing the spillage of wood chips during the loading of barges, and the possible relocation of the dip tank from the bank of Mamquam Blind Channel.

5.1.2 Woodfibre (formerly owned by Rayonier Canada Ltd.)

Although this operation is outside the study area, its close proximity and the effect of its air emissions on the study area make it worthy of comment.

(a) Plant Operation

The mill was built in 1912 as a sulphite pulp mill. The mill was converted in the period between 1959 and 1961 to a bleached kraft mill. In 1965, the bleached kraft capacity was increased to 545 air dried tonnes per day through the addition of a continuous digester, brown stock washing, screening and bleaching plants.

A simplified flow diagram for the plant operation is shown in Figure 14. Wood chips used in the process enter on two process lines. The operating principles of both lines are the same, except line 1 utilizes five batch digesters in place of the continuous digester utilized in line 2. After passing through the digesters, the brown stock is washed and screened, prior to bleaching. After undergoing bleaching, the product is dried.

(b) Air Emissions

Monitoring data obtained by the company, as well as a summary of per-

mitted values for contaminants under pollution control permit PA 1647, are included in Table 3. Emissions from the fuel oil fired power boiler stack and the lime kiln and dissolving tanks consistently met permitted values.

The data in Table 3 indicate that emissions from the recovery boiler consistently exceeded the permit values for suspended particulate matter. Bivalent sulphur compound values also exceeded permitted values, 92% of all recorded values exceeding the average permitted value of 20 parts per million by volume (ppm_v), while 25% of all values exceeded the maximum permitted value of 70 ppm_v.

Emissions from the wood waste fired power boiler stack also exceeded permitted values. Analyses for particulate matter exceeded the permitted average value of 16.6 mg/mol at 12% CO_2 during every yearly quarter when measurements were made, as well as exceeding the maximum permitted values of 24.9 mg/mol at 12% CO_2 during all but one yearly quarter.

The odour problem noted at Squamish would likely be less severe if permitted values for bivalent sulphur compounds at this operation were met, although it is unlikely that the odour problem can be completely eliminated due to the low threshold odour concentration for bivalent sulphur compounds.

(c) Recommendation

The company should take the necessary steps to meet the conditions of its pollution control permit for air emissions.

5.1.3 Reichhold Limited

(a) Plant Operation

Reichhold Limited is constructing a bark conversion plant on a 1.8 hectare site located adjacent to the Weldwood Empire Lumber Sawmill, between Highway 99 and B.C. Rail Line (Figure 12). This operation is scheduled to begin in late 1980. It will produce approximately 14,500 tonnes per year of dried, ground, and bagged Hemlock bark, from bark wastes from the Weldwood Empire Sawmill. The end product, produced elsewhere, will be a resin glue extender which will subsequently be used in the manufacturing of plywood. The

product will be marketed throughout British Columbia and the north-western United States.

A simplified flow diagram of the bark conversin plant process is shown in Figure 15. Bark will be transported through an enclosed blowline from the sawmill to a bark storage silo at the plant site. The bark will then be passed by conveyor to a natural gas heated, three pass low temperature ($\approx 100^{o}C$) rotary drier where the moisture content of the bark will be reduced from approximately 65% to 5%. The dried bark will be blown into a two stage cyclone system for separation from drier exhaust gases. A portion of the drier gas will be recycled back to the drier, while the remaining gas will be vented. The drier gas will consist mostly of water vapour, air and a small volume of suspended particulate matter. No problem of odours is anticipated from this process since drier temperatures will be low.

The dried bark will be passed to a surge box from which it will constantly be fed to three grinders. The grinders will reduce the bark particles to a size less than 25 mm. Fine particles from the grinders will be prevented from leaving the plant by using cloth bag filters. After grinding, the bark will be sorted. Unsuitably sized pieces will be rejected and passed to a storage silo to await disposal at the Empire Lumber solid waste disposal site. The remaining processed bark will then be mixed and passed to a storage hopper. The processed bark will then be forced flow packed into bags for shipment. The product will be shipped by rail or truck to market.

(b) Air Emissions

This operation will have no liquid effluent discharges, although two air emissions will be permitted under pollution control permit PA 5765. These emissions will be treated using double cyclones on the drier exhaust and dacron cloth bag filters on the grinders. Due to the proximity of residences (350-500 metres from the plant), and since this is a new operation, emissions for particulate matter will be required to meet level "A" Objectives of 2.8 mg/mol. The permit limits and monitoring criteria are summarized in Table 4.

5.2 Chemical Industries

The Pollution Control Board issued Pollution Control Objectives for the

Chemical and Petroleum Industries of British Columbia in 1974. The Objectives outlined three levels as minima, level "A" for all new operations, level "C" for existing operations, and level "B" as an intermediate level in upgrading existing operations to level "A".

5.2.1 F.M.C. of Canada Ltd.

This company holds three pollution control permits. These permits deal with air emissions (PA 1711), liquid effluents (PE 138) and sludge solids disposal (PR 1627). Each permit is discussed in sections (b), (c) and (d) respectively. A history for each permit is also presented therein.

(a) Plant Operation

F.M.C. of Canada Ltd. has operated a chlor-alkali plant near Squamish since 1965 (Figure 12). The plant was designed to produce 135 tonnes per day of chlorine and 310 tonnes per day of fifty-percent caustic soda (NaOH) (Beak Consultants Ltd., 1978b). Hydrogen is a product of the process and is used to make muriatic acid (HCl). Expansion of the cell area in 1976 allowed the production of 180 tonnes per day of chlorine, 195 tonnes per day of one-hundred percent caustic soda and 25 tonnes per day of thirty-two percent muriatic acid (Beak Consultants Ltd., 1978b).

Figure 16 is a simplified flow diagram for the process and the mercury recovery system, both of which were outlined in a report by Beak Consultants Ltd. (1978b) and are summarized below. The neutralization tower for reduction of chlorine bases is also shown. The basis of the process is the electrolysis of purified brine to obtain chlorine and sodium, followed by the hydrolysis of the sodium to produce caustic soda (NaOH). Hydrogen is released as a by-product and is used to make muriatic acid (HCl).

The electrolytic cell consists of metal anodes suspended in troughs through which flow mercury (cathode) and the purified brine. When a current is applied, chlorine and sodium-mercury amalgam are produced. The chlorine is cooled, dried with sulphuric acid, compressed and condensed to obtain the liquid chlorine product. This is subsequently sold to pulp and paper plants. The sodium-mercury amalgam is passed to a secondary cell or decomposer which

is packed with graphite plates. Upon the addition of water, the amalgam decomposes to form caustic soda and mercury. Almost pure hydrogen is also released. The mercury and any remaining brine are recycled. The caustic soda is cooled, filtered to remove mercury and loaded for shipment to pulp and paper mills. The hydrogen is cooled, passed to the demister and molecular sieve for mercury removal and combined with chlorine from miscellaneous sources (purging empty rail cars, chlorine vent gas and chlorine blow gas) to produce muriatic acid. Muriatic acid is used principally for steel pickling and asphalt manufacture (Beak Consultants Ltd., 1978b).

The mercury which is separated from the hydrogen and caustic soda is entrained in cooling water. The cooling water is treated in the mercury separator using sulphide precipitation to remove mercury, and is then discharged to the effluent pond (Figure 17). The reclaimed mercury is recycled back to the cell.

Recycled cooling water is used to reduce mercury vapour loss from the inlet and outlet boxes of the electrolytic cell and from the mercury pump seals. The water is circulated around these areas to entrain any mercury. Excess water is passed with the cooling water to the mercury separator.

The cell ventilation exhaust which withdraws mercury and water vapours generated in the cell area and which was formerly discharged through a stack, is now treated for mercury removal. A demister and molecular sieve were installed as required by the November 1977, amendment of the permit. The trapped mercury is entrained in cooling water and passed to the mercury separator.

The sludge generated in the process consists of precipitates from brine clarification. The recycled brine is contaminated with mercury which is precipitated, resulting in mercury contamination of the sludge. The mercury is partially removed by hypochlorite leaching.

Approximately 99 percent of the mercury is removed from the cooling waters in the mercury separator, 99.9 percent from the cell ventilation exhaust and 98 percent from the sludge. This suggests that the mercury recovery system is effective (Beak Consultants Ltd., 1978). The remaining mercury quantities in the effluent, air emissions (particularly the cell ventilation exhaust, hydrogen

stack and diffuse cell room losses) and sludge are discussed in Sections 5.2.1 (b), (c) and (d). However, there is still about 80 percent of the mercury which has to be added to the system which cannot be accounted for (Figure 18). This loss is most likely due to diffuse vapour loss in the cell area. However, this is difficult to determine since it is not a closed area. Beak Consultants Ltd. (1978b) conducted studies to determine the diffuse losses, and estimated the loss in 1977 to be about 1.36 kg per day (kg/d). This represents only 18.3 percent of the mercury unaccounted for in 1978, and 18.6 percent of the mercury unaccounted for in 1979. Thus, there still remains 2 212 kg of mercury unaccounted for in 1978 (6.1 kg/d) and 2 195 kg of unaccounted mercury in 1979 (6.0 kg/d). Discussions with the Environmental Protection Service, the Waste Management Branch and the company are ongoing to resolve this mercury loss.

In addition to the mercury recovery system, treatment works to reduce residual chlorine in the effluent and gaseous chlorine in the air emissions were undertaken. Treatment is accomplished in the neutralization tower (Figure 16) which is a packed tower with a cooled circulating solution of sodium hypochlorite-sodium hydroxide (Beak Consultants Ltd., 1978b). Chlorine from purging of empty tank-cars and uncondensed blow gases, which are not used for muriatic acid production, and from various seals in the chlorine system, is collected and passed to the neutralization tower where it is absorbed and neutralized (Beak Consultants Ltd., 1978b). To reduce the likelihood of chlorine spills, the neutralization tower has the capacity to handle the plant's entire chlorine production for a period from 20 to 30 minutes. The chlorine levels in the effluent and air emissions (particularly the neutralization tower) are discussed in Section 5.2.1 (b) and (c).

(b) Air Emissions

Pollution control permit PA 1711 was issued in June 1973 and subsequently amended in July 1974, and November 1977. The original permit was for six emissions. The first amendment was to accomodate the higher than predicted emission rates from the hydrogen stack. The second amendment dealt with required modifications to reduce mercury vapour losses, particularly from the hydrogen stack and the cell ventilation exhaust. It also stipulated ambient air levels in the cell room.

Monitoring data related to this operation for 1979 and 1980 have been included in Table 5. Emissions from all stacks, as well as ambient air values at the plant boundary and Pemberton Street, met the permit conditions. However, ambient air concentrations of mercury were sometimes in excess of permit values in the cell room areas. Chlorine emissions from the caustic scrubber stack exceeded the maximum permitted value of 3.0 ppm_v for some instantaneous recorded values.

The mercury content of dustfall at two stations at the north property line of FMC was measured in September and October 1930, to assess how much mercury in the settleable size range was escaping from the plant. The results are included in Table 5. If the data for station 2 are representative of a one kilometre radius from the plant, the total mercury in the area would be 0.1 kilograms per month. Additional monitoring should be carried out to determine the effects of variations in weather and plant operating conditions.

(c) Liquid Effluents

Pollution control permit PE 138 was issued to the company in 1965 for the disposal of process wastes which consisted of a sludge slurry. The permit required discharge of the sludge slurry to a settling pond and stipulated that additional land be set aside for a future pond. By 1970, the first settling pond was essentially full and the effluent pond was excavated. The company at that time began the practice of drying the sludge and discharging wastewater through the effluent pond. The sludge solids are discussed in Section 5.2.1 (d).

Increased awareness about the toxicity of mercury in approximately 1970, as well as the high values of mercury in the sludge slurry, air emissions, and receiving environment resulted in the installation of a mercury recovery system by FMC. The mercury recovery system reduced losses of mercury vapour within the manufacturing process, the cooling water, and air emissions, and mercury which leaches from the dried sludge.

The process cooling water and the filtrate from the mercury recovery system are discharged to the effluent pond (Figure 17). The pond provides a twelve hour retention to the effluent. The effluent from the pond is discharged to Howe Sound, and is covered by pollution control permit PE 138.

The monitoring data for the period from 1972 through March 1980, for F.M.C. of Canada Ltd. are given in Table 6. Included are the results for the cooling water, the filtrate from drying the sludge, the discharge to the settling lagoon and effluent discharged from the effluent pond. Mercury showed a noticeable reduction in value between the influent and effluent streams, from a mean value of 20 µg/L in the influent, to 3 µg/L in the effluent. This suggests that the pond may be effective in reducing the mercury, however this is based upon limited data for the influent.

The mean values for residual chlorine, hydrogen peroxide, mercury, pH, sulphide, and suspended solids were all within the permitted ranges outlined in pollution control permit PE 138. However maximum values recorded in the effluent for residual chlorine, hydrogen peroxide, mercury, and suspended solids exceeded maximum permitted values. As well, both minimum and maximum pH values were outside of the permitted range. To determine the frequency of measurements in excess of the permit level, the cumulative percent occurrence of the concentrations for each parameter were calculated and plotted in Figure 19. Each parameter had over 2000 measurements and the percent of the values greater than the stipulated level was less than one percent, except mercury (4.4 percent) and flow (18.7 percent). FMC produce monthly and quarterly reports for regulatory agencies which attempt to explain excursions in values and report on investigations undertaken.

Analytical results for trace organic contaminants in an effluent sample collected in November 1980, are discussed in Section 5.7.2.

The possible leaching of mercury to the marsh adjacent to the effluent pond to Cattermole Creek and the possible tidal intrusion of mercury in the effluent to Cattermole Creek are considered in Chapter 9.

FMC have conducted 96-hour static bioassays using rainbow trout and effluent samples from the effluent pond four times yearly since the third quarter of 1972. The data indicate that in all tests, at least 70% of the fish survived in undiluted effluent. This corresponds to a 96-hour LC_{50} of greater than 100%. Furthermore, twenty of the twenty-eight samples indicated no toxicity to the fish after 96 hours.

(d) Solid Wastes and Groundwater Concerns

The sludge slurry and process wastes were discharged to a settling pond during the period 1965 to 1970, as allowed by pollution control permit PE 138. The changes in treatment of wastes made by the company in 1970, and cited in Section 5.2.1 (c), resulted in the sludge solids being discharged to the solid waste disposal site.

Pollution control permit PR 1627 allows the disposal of the sludge filter cake, or those solids which remain after the extractable mercury has been leached and sludge dried. The pollution control permit required the installation of an impermeable layer under the sludge filter and disposal site, to prevent leachates reaching the groundwater. It also required intermediate covering of the sludge each disposal day (discontinued in 1975 due to space restraints), adequate fencing around the disposal site, and the monitoring of mercury concentrations in the sludge and in groundwater from test wells located adjacent to the disposal site. As well, the sludge was to be mixed with sand in the proportion of sixty percent sand to forty percent sludge. These requirements were fulfilled by the company by 1974.

The sludge filter cake was disposed of in the solid waste disposal site (identified as abandoned in Figure 17) during the period from 1970 to 1978. This initial site was filled and covered with a PVC sheet, and sand. Regular monitoring of test wells adjacent to the abandoned site should continue so that the permeability of the PVC sheet, and the effect of the sheet in preventing downward seepage and contamination of groundwater, can be studied.

A new solid waste disposal site, adjacent to the first, was excavated in 1978. It was underlaid by PVC sheeting in an attempt to prevent the commination of groundwater. Water which pools as a result of the PVC sheeting is currently collected and trucked back to the plant for treatment in the mercury recovery system.

A data summary of the mercury analyses of the sludge, performed by the company, and reported to the Waste Management Branch, is included in Table 7. The data indicate that since plant expansion during 1975 and 1976, the total mercury disposed of with the sludge has approximately doubled. It is projected, based upon data for the period from January through July of 1980, that 70 kilograms of mercury were discharged with the sludge during 1980.

FMC has located test wells adjacent to the abandoned settling pond and the abandoned solid waste disposal site. The locations of these test wells are indicated in Figure 17. The analytical mercury data are summarized in Table 8.

Concern has been expressed about the potential exfiltration of mercury from the abandoned settling pond to Howe Sound. Data for the test wells immediately adjacent to the abandoned settling pond indicate that the highest recorded mercury values were found in wells F, G, H, K and L, all of which had median values during 1978 exceeding 700 µg/L. This compares to test wells A, B, C and D, which could be classified as controls, and which had median mercury values during 1978 of from 0.4 µg/L to 1.6 µg/L. This indicates that mercury is still exfiltrating from the sludge deposited before 1971 into the abandoned settling basin. As well, data collected in 1979 by the Waste Management Branch (Table 49B) indicated that seepage contained as much as 750 µg/L mercury. However, the exfiltration rate is unknown.

The fact that mercury continues to exfiltrate from the abandoned settling pond initiated discussions between the Waste Management Branch and the company as to what methods might be used to stabilize the material in the settling pond. The company is currently attempting to isolate the sludge, contain and cover it with a temporary impervious membrane, and research sludge stabilization methods. It is anticipated that this program will be completed during 1981.

Monitoring data for the period 1975 to 1978, related to groundwater quality at three test wells located adjacent to the abandoned solid waste disposal site, are summarized in Table 8. The data indicate median mercury values of approximately 1 µg/L in the three wells (EE, NW, SW), similar to median values found at the four control stations (A, B, C, D). However, maximum values at test wells EE, NW and SW, exceeded the maximum recorded values for test wells A, B, C, and D, by factors of from 2 to 4. These data indicate that there would not normally appear to be contamination of the groundwater from the solid waste disposal site.

(e) Recommendation

FMC should, during 1981, complete the program undertaken to isolate the sludge in the abandoned settling pond, and contain and cover it with a temporary impervious membrane.

FMC should continue, as a minimum, a monthly monitoring program of the test wells adjacent to the abandoned settling pond in order to ascertain the effectiveness of placing cover over the abandoned pond. The operation should seek to stay within the limits of its pollution control permits.

5.2.2 CanadianOxy (Hooker) Chemicals Ltd.

(a) Plant Operation

Hooker Chemicals Ltd. operates a sodium chlorate plant which produces approximately 10 900 000 kg/yr of liquid sodium chlorate by the electrolysis of brine. Operations at this plant commenced in early 1973 under the ownership of Squamish Chemicals. Hooker Chemicals Ltd. assumed ownership of this plant in late 1975 and changed its name to CanadianOxy in June 1980. The plant is located on the east bank of Cattermole Creek, to the north of FMC Canada Ltd. (Figure 12).

A simplified flow diagram of the plant process is shown in Figure 20. A saturated solution of brine is mixed, and then treated with sodium hydroxide (NaOH) and sodium carbonate (Na_2CO_3). This solution is passed to the brine clarification tank were insoluble salts which have formed (primarily calcium and magnesium) precipitate out.

The sludge from the brine clarifier (Ca and Mg precipitates) is periodically removed and discharged without treatment to a landfill on the property. Due to the presence of sodium hydroxide and sodium carbonate, the sludge is basic (pH approximately 10).

The clarified saturated brine solution is stored in three tanks where sodium dichromate ($Na_2Cr_2O_7$) is added. The saturated brine is then passed to electrolytic cells, where a weak solution of hydrochloric acid (HCl) is added.

The sodium dichromate is added to the process to reduce the corrosiveness of hypochlorous acid which is formed. In the electrolytic cells, this plant differs from most by the use of metallic electrodes (Titanium alloy), instead of the more conventional graphite electrodes. This results in the absence of a graphite mud discharge.

The products of electrolysis, sodium hydroxide at the cathode and chlorine at the anode, undergo mixing with the formation of sodium hypochlorite (NaOCl), which in turn is oxidized to sodium chlorate ($NaClO_3$). The finished cell liquor (sodium chlorate solution and impurities) is treated with urea to destroy any remaining hypochlorite. The aqueous product (solution of approximately 650 grams/litre sodium chlorate) is stored to await shipment by rail to market. The only process water discharged is that which is lost in the disposal of the precipitates from the brine clarifier since the product is sold as a solution rather than as a solid.

(b) Air Emissions

Air emissions originate from the electrolytic cell area, and are composed mainly of hydrogen and chlorine. The emissions pass through a caustic scrubber where the gaseous chlorine is scrubbed with a solution of sodium hydroxide, and the emissions are discharged from one stack. Sodium chloride, and sodium hypochlorite which are formed, are recycled into the brine saturation process.

The company is allowed by pollution control permit PA 1701 to discharge 785 mol/s, of which 765 mol/s is air and water vapor. The air emission monitoring summary has been included in Table 9. It indicates that the maximum value for chlorine emissions of 10 ppm was not exceeded during either 1978 or 1979. No total particulates were measured in the emissions in the period 1974 to 1976.

(c) Liquid Effluents

The electrolytic cells are cooled by a cooling water circuit. Water from the circuit was discharged through a submerged outfall into Cattermole

Creek until 1980. At that time, a closed-loop type cooling system was installed. This precluded the discharge of cooling water.

The data in Table 9 indicate that the discharge of cooling water was always less than that permitted (6 820 m^3/d). The high total solids values reflect the use of the water from Cattermole Creek for cooling. The source of water changed to the District of Squamish Waterworks with the initiation of the closed loop system. The temperature of the cooling water ranged from 27°C to 57°C. The elimination of this discharge should therefore eliminate the localized effects which would have been associated with the discharge.

The discharge of the brine sludge to the landfill was allowed by pollution control permit PE 1700. It restricted the flow to 0.9 m^3/d and the pH to the range from 5 to 10. The data in Table 9 indicate that the pH range was met.

(d) Non-Point Sources

The Waste Management Branch has measured elevated chromium levels in the ditch water adjacent to the landfill site. These may be attributed to seepage from the landfill. This ditch water discharges to Cattermole Creek.

(e) Recommendations

The Waste Management Branch should continue to sample the ditch water adjacent to the landfill site. The results of this sampling program should form the basis for any action taken by the company to alleviate any leachate discharge.

5.3 Port Facilities

5.3.1 Squamish Terminals

(a) Operation

Squamish Terminals has operated one deepsea berth and one barge slip

for forest products, on a 17 hectare site in the eastern portion of the Central Basin (Figure 12), since 1972.

(b) Liquid Effluent

Wastewater is the major pollution concern from this operation. Oil is recovered from floor wash water and steam cleaning pad water through the use of oil separators. Floor wash water is treated by an oil separator within the terminal building, while steam cleaning pad wastewater flows to another oil separator outside the building.

Oil separators cause oil to rise to the liquid surface while water forms the lower liquid layer. Particulate oil and other hydrocarbons form a surface layer between baffles. The surface layer is removed by pumping, and is trucked to the landfill site.

The effluent from the separators is drawn off from the separator bottom, and is pumped to a rock seepage pit which has been enlarged to accomodate a flow of 2.3 m^3/d.

The discharge of effluent from the oil separators to the rock seepage pit is authorized by pollution control permit PE 1749. A summary of monitoring data, as well as limits contained in pollution control permit PE 1749, are included in Table 10. The limited data indicate that the permitted value for oil and grease was exceeded for 46% of the data. The mean oil and grease value was about 150 mg/L.

(c) Non-Point Sources

Squamish Terminals operate a wood preservative plant utilizing a solution of pentachlorophenol at this site. Samples of sediments from points of yard runoff were taken in September 1980. The results of these samples are summarized and discussed in Section 10.1.6.

(d) Recommendations

The company should take steps to improve the recovery of oil so that

the limit for oil and grease, outlined in the permit, is met. As well, periodic inspections of the zone of influence of the rock seepage pit on the intertidal zone, should continue to be made by the Waste Management Branch.

5.4 Municipal Sewage Treatment Plants

(a) Plant Operation

The District of Squamish operates two high rate activated sludge secondary treatment facilities within the study area.

The Central Squamish Sewage Treatment Plant (STP) (PE 1533) was constructed in late 1972 to serve the downtown area, dock area, Valleycliffe, Wilson Crescent, and North and South Ridge. The plant was designed for flows of 4 545 m^3/d, from a population equivalent to 10 000 people.

The Mamquam STP (PE 1512) began operating in early 1973. It serves the north Mamquam area, Garibaldi Estates, Highland Subdivisions, portions of Paradise Valley, B.C. Rail shops, and the northerly portion of Mamquam South. The plant was initially built for a design flow of 2 270 m^3/d and was later expanded for flows of 5 450 m^3/d.

A simplified flow diagram of the two plants is presented in Figure 21. Raw sewage is pretreated with coarse screens, a comminuter, and for grit removal. A screw pump is used to lift the sewage into the plants to a sufficient height to allow gravity flow through the plants. A floating device has been installed in the screw pump well at the Mamquam STP, to contain oil and grease and prevent it from entering the remainder of the treatment works.

The coarse screens strain solids which, if allowed entrance, could interfere with the treatment process. Grit particles are removed through sedimentation in a controlled velocity chamber, from where the grit is manually removed. Grit removal prevents deterioration of pumps, the comminuter, and decreases solids deposition in pipelines, tanks, and the digesters. The comminuters grind the waste solids into smaller particles, thereby increasing the efficiency of pumping and of the activated sludge process.

"Activated sludge" describes a continuous flow biological treatment system, characterized by a suspension of aerobic micro-organisms maintained in a homogeneous state, by mixing and turbulence induced through aeration. The micro-organisms present in the suspension oxidize soluble and colloidal organics in the presence of molecular oxygen. During this process, a portion of the organic material is synthesized into new cells, which undergo auto oxidation (endogenous respiration) in the aeration tank.

To operate this process on a continuous basis, solids generated in the aeration tank are separated in the clarifier. Most of these settled solids are returned to the aeration tank. Excess solids from the clarifier are withdrawn from the clarifier underflow, and passed to the aerobic digesters. In the aerobic digesters the sludge is aerated to achieve a reduction in pathogenic organisms, grease and hexane solubles, total phosphorus, and a supernatant of lowered BOD_5, that can be recycled back to the aeration tank. With aerobic digestion, a reduction of volatile solids of up to 50% can be achieved, depending on the temperature and retention time of the process. Sludge from the aerobic digesters is removed by pumping, and is trucked to landfill sites in Squamish.

The clarified effluent passes to the chlorine contact chamber where chlorine is added. Highly efficient disinfection is best carried out in effluent free of suspended solids. High suspended solids may result in bacteria present in the solids not being killed. Suspended solids concentrations and bacteriological values in the effluents are discussed in Section 5.4 (b).

(b) Liquid Effluent

A summary of monitoring data, as well as permitted values for the Mamquam STP (PE 1512) and the Central STP (PE 1533), are included in Tables 11 and 12.

The mean values for five-day biochemical oxygen demand (BOD_5) and suspended solids at the Central STP (PE 1533) met permit values. However, maximum recorded values for both of these constituents exceeded permit values.

The effluent from the Mamquam STP (PE 1512) did not meet permit levels

for BOD_5 and suspended solids for over fifty percent of the monitoring data. It is believed that this non-compliance could result from high rates of infiltration into the sewage system. This has been a problem in the operation of both plants since instantaneous flows in excess of the plant design regularly occur, but cannot be recorded on the flow monitoring equipment (R. Mihalick, personal communication). High flows are also reflected in the flow data in Table 12.

Higher than anticipated flows would wash out the biological floc from the activated sludge section of the plant, rendering the treatment process nearly useless. This is typified in the effluent data by BOD_5 values of over 200 mg/L, and suspended solids values of over 1 000 mg/L, values of BOD_5 one might anticipate in a sewage plant influent. The suspended solids values are excessive of what would normally be present in an influent, indicating that the sludge is being washed out from the plant. One solution to the problem of these instantaneous high flows would be to place a flow equalization chamber ahead of the treatment works to even out the extremes in flow presently entering the plant.

Flow equalization facilities should also be considered for the Central STP, which has flows of approximately 20 m^3/d less than are recorded for the Mamquam STP (R. Mihalick, personal communication). As well, the plant has had BOD_5 values recorded as high as 135 mg/L, and suspended solids values of nearly 400 mg/L in the effluent. Permitted levels are 30 mg/L for BOD_5 and 40 mg/L for suspended solids.

The data reported by the District of Squamish for bacteriological quality of the effluents are significantly lower than values recorded throughout this study by the Air and Water Quality Work Group. Samples taken by the District of Squamish for analysis are collected in bottles which do not contain sodium thiosulphate (EVS Consultants, personal communication). Sodium thiosulphate would neutralize the chlorine present in the sample. Failure to add the sodium thiosulphate would permit residual chlorine to continue killing bacteria in the sample. This in turn would not permit accurate results to be obtained.

The presence of chlorine in the effluent has been recorded. The Squamish Central STP effluent had a mean chlorine residual of 0.9 mg/L, while the Mamquam

STP effluent had a mean chlorine residual of 0.74 mg/L. Chlorine residuals as high as 3 mg/L have been recorded in both effluents. Chlorine residuals in excess of 0.02 mg/L are toxic to certain salmonids. The need for dechlorination should be considered in conjunction with the present chlorination practises, however a general review of these practises may be warranted.

The mean recorded values for Kjeldahl and ammonia nitrogen at the Mamquam STP were greater than those recorded at the Central STP. However, maximum recorded values were of the same order of magnitude. It is not known if the higher mean values at the Mamquam STP were related to the larger data base for that plant.

A site inspection in October 1980 of the outfall from the Mamquam STP indicated that the Squamish River was not flowing in the channel in which the outfall is located. This inspection followed a dredging program undertaken by the District of Squamish designed to rectify this situation which had been noted in earlier inspections. The lack of water in the channel necessitates that the undiluted effluent flows over the dry stream bed for a distance estimated at 300 metres, before reaching Squamish River. This is unacceptable from a human health perspective as bacteriological counts in the effluent are high. As well, the requirement for a minimum 20:1 dilution of effluent is not immediately met which may be a problem for some salmonid species in the stream.

Over a six day period in July 1980, 12 hour composite samples of the effluent from the Mamquam STP were collected. Analyses indicated ammonia levels to range between 24 and 27.4 mg-N/L (median 25.7 mg/L), with pH values ranging between 7.4 and 7.6 (median value 7.5), and a temperature range of 16.0 to 18.5^{o}C. Ammonia levels recorded during July would be expected to decrease during the winter due to diluted sewage flows during that period.

Table 13 indicates the estimated concentrations of undissociated ammonia over the range of ammonia concentrations observed, at variable temperatures and pH. The levels observed were always in excess of the water quality criterion of 0.02 mg/L un-ionized ammonia (0.016 mg/L as N) (EPA 1976). This implies that the effluent (plume) is potentially toxic to aquatic life. For maximum observed values, approximately 0.34 mg-N/L of undissociated ammonia would be present in the effluent. At this level, an instantaneous dilution of

approximately 18.1 would be required to eliminate the ammonia toxicity at the outfall assuming temperature and pH were the same as the effluent. With river waters at low pH and temperature as is often the case, less dilution would be required to prevent ammonia toxicity. Conversely, greater dilutions would be required if the river had a higher pH or temperature. This is discussed in Section 8.1.3.

Analytical results for a sample of Mamquam STP effluent collected in November 1980 and analyzed for trace organic contaminants, are discussed in Section 5.7.2.

(c) Recommendations

Flow equalization facilities should be considered at both sewage treatment plants to improve plant performance and thus effluent quality, as measured by BOD_5 and suspended solids. As part of this program, an evaluation of the present flowing metering equipment should be undertaken.

Collection methods for chlorinated effluent samples for bacteriological analysis should be revised to ensure that sodium thiosulphate is used. As well, the need for chlorination and dechlorination of the sewage treatment plant effluents should be addressed.

The outfall from the Mamquam STP should be extended to a point in the Squamish River which ensures adequate dilution of the effluent at all times.

5.5 Municipal Refuse Disposal Sites

(a) Permit History and Site Description

The District of Squamish operated a municipal refuse site until June 1980. The location of this site is shown in Figure 12. This site was never granted a pollution control permit due to its unacceptable location.

The site covered an estimated 3.5 hectares of low lying land within the protective flood dykes of the Squamish District. The water table at this site occurred at approximately 30 cm, according to Ministry of Environ-

ment files. Ground water emerged at several locations.

The Squamish River flows past the landfill approximately 900 metres to the northwest. Tidal backchannels come within 300 metres of the northern and southern site boundaries. Along the western boundary is a slough area which is crossed by the BCR rail line, and which drains into a tidal channel an estimated 100 metres to the south. The eastern boundary of this site is a dyke which serves as an access road. A drainage ditch which borders the dyke enters a tidal channel approximately 100 metres south of the site.

(b) Non-Point Sources

Inspections of the refuse disposal site in May and June 1980, a period of low precipitation, indicated surface leachate seepage occurring on the west, east and north dump faces. Most of the leachate from the north and east faces went through culverts into the drainage ditch, along the side of the dyke and entered tidal waters. Garbage landfilled into standing waters adjacent to the railway tracks was a potential leachate source to receiving waters. However, the railway tracks may have formed an impermeable dyke limiting any leachate flow westwardly into a nearby slough. A small swamp located in the southeast corner of the site contained a thick oily deposit. This swamp was isolated from the nearby slough by the railway tracks to the west. Thus, seepage was prevented from entering the slough.

Coverage of the active dumpfaces was sparse. A large quantity of wastes had been strewn by animals and winds throughout the area. However, a site inspection in October 1980 revealed that this situation had been rectified.

To date no leachate samples have been taken from the dump site. Since the leachates could enter the estuarine system, samples should be taken to assess their toxicity and zone of influence. Methods of limiting any further leaching to the estuary should be investigated.

Several authors, Merz and Stone (1967) and Stone and Gupea (1970), have discussed potential problems of methane buildup from municipal refuse sites.

Potential problems of this kind at the Squamish refuse site will be related to the length of time that the site was in operation, the types of materials landfilled, and levels of groundwater.

(c) Recommendations

The potential methane generation at this site should be assessed if future development is planned at the site, or on adjacent lands. As well, methods of limiting the entry of leachates into the estuary should be investigated and co-ordinated with any program undertaken to assess their zone of influence and toxicity.

5.6 Mining Operations

5.6.1 Britannia Mines

Between 1899 and 1974 a copper-zine mine at Britannia discharged mine tailings into Howe Sound via Britannia Creek. When the mine closed in 1974, leachate containing metals continued to discharge from inside the mine.

In 1978, a 25-foot thick hydrostatic dam was built 1 400 feet inside the 4 100 foot portal. The effect of this dam was to reduce copper levels from 48 mg/L to 7 mg/L, and zinc levels from 39 mg/L to 22 mg/L at that time. Later the same year, the company installed a submerged outfall, at a depth 180 feet below high tide, from which the mine leachate flow (68 000 m^3/d, maximum) was discharged.

In late 1980, the Director of Pollution Control ordered that all internal mine drainage must be directed to the 4 100 foot portal, and that the leachate receive treatment when the total copper concentration exceeded 15 mg/L.

Recent improvements at the site have included the collection, treatment and discharge of domestic waste (210 m^3/d) from the submerged outfall.

5.7 Miscellaneous

5.7.1 Storm Sewers

Miscellaneous discharges entering Mamquam Blind Channel were sampled

during June and July 1980. A brief description of each discharge and the results of sample analyses are summarized in Table 14. The locations of these discharges are given in Figure 22.

Phenol levels in storm sewer discharges ranged from 0.002 to 0.012 mg/L. These levels exceed surface water phenol values in the Mamquam Blind Channel, all of which were less than 0.002 mg/L. The culverts draining the eastern portions of the Weldwood mill site, and the Weldwood dryland log sort had the highest phenol values (0.012 mg/L). The dryland log sort culvert had the highest level of tannin and lignin (25 mg/L) measured. No data for tannin and lignin were available for the mill site culvert, and the other storm sewer discharges had recorded values from 0.6 to 3 mg/L.

Oil and grease analyses were performed on two of the discharges. A small culvert draining the ESSO tank farm had an oil and grease level of 1.7 mg/L, while the culvert draining the eastern Weldwood mill site had a concentration of 6.2 mg/L, the highest level recorded.

Fecal coliform values were high in all the discharges sampled. The culvert draining the motel area had a value of 1 700 MPN/100 mL, while the Weldwood office drainage and Weldwood mill culvert had values of 3 500 MPN/100 mL and >24 000 MPN/100 mL, respectively.

The Weldwood office drainage was seen to have a milky appearance.

5.7.2 Trace Organic Contaminants in Discharges

In order to obtain preliminary information on the occurrence of trace organic compounds in different types of discharges, samples of effluent from the Mamquam STP and FMC of Canada, and of dry weather yard drainage from Weldwood of Canada were collected in November 1980. The data are reported in Table 65, and the approximate location where the yard drainage sample was collected is indicated in Figure 31.

Eighteen different trace organic compounds were detected in the discharges, although only ten of these compounds could be quantified. This com-

pares to twenty-eight different compounds detected at Greater Vancouver Regional District sewage treatment plants, however only fifteen of those compounds could be quantified (Cain et al., 1980).

Compounds detected in all three discharges were chloroform, bis (2-ethylhexyl) phthalate, benzene hexachloride (gamma), butyl benzylphthalate, di-n-butylphthalate, diethylphthalate, and dimethylphtalate. Compounds detected in only one or two discharges included methylene chloride, napthalene, pentachlorophenol, trichloroethylene, 1,1,2-tri chloroethane, di-n-octyl-phthalate, 1,3- dichlorobenzene, toluene, aldrin, bromoform and benzene hexachloride (alpha).

All of these compounds are man-made, and most are listed under the Environmental Contaminants Act as priority chemicals or on the candidate chemicals list. Generally, these compounds are very persistent in the environment. An example of this is benzene hexachloride (gamma) which has not been used as a pesticide in log sorting for approximately ten years. It is recommended that an additional survey be initiated to ascertain the source and loading of these substances to the estuary, any bioaccumulation in the environment, and practical steps which might be taken to minimize the discharge of these chemicals.

VI Hazardous Chemicals

6. HAZARDOUS CHEMICALS

6.1 Transport and Storage

Bulk quantities of chemicals are handled largely by the chemical and forest industry operations. The major chemicals handled in the area are listed in Table 15.

The information in Table 15 indicates that approximately equal quantities of chemicals in the form of chlorine, sodium hydroxide, and sodium chlorate are shipped out of Squamish by truck, barge, or rail. Only minor quantities of chemicals are brought into Squamish relative to the quantities of these materials shipped out of the Squamish area. Approximately 70% of these imported chemicals are transported by truck, and the remainder by rail. The chemicals used in largest quantities at Woodfibre (Table 16) are generally transported by barge or rail.

Liquified petroleum gas (LPG) is distributed by Squamish Gas Limited (Schultz International, 1979). They have four stationary horizontal storage tanks of 113, 560 litre capacity. The LPG is shipped to Squamish by rail and unloaded in a siding adjacent to the storage tanks.

Failures of storage tanks are rare. Between 1944 and 1973, only eleven serious LPG tank ruptures were reported to the National Fire Protection Association for all of North America. The shipping and unloading operations present some risks for explosions and/or fire.

There were five derailments in the Squamish area between January 1975 and June 1979 out of 9230 trains passing through the area. While these were not necessarily serious derailments, incidents other than derailments could cause fires or explosions. These include collisions of railway cars with road vehicles at level crossings, or collisions with each other as they are being shunted.

6.2 Spills

Recorded spill incidents for the period from 1973 to 1978 are presented in Table 17. The largest recorded spill was at the Woodfibre operation when 2 727 metric tonnes of vanillin liquor was spilled in 1974. No further information related to clean-up action undertaken is available.

The largest number of reported spills have related to spills of Bunker C oil.

Chlorine leaks from storage and loading facilities at FMC and Hooker (CanadianOxy) Chemicals occur occasionally. There is a documented case of a release of 0.44 tonne of chlorine from FMC in 1977 (Table 17).

The likelihood of a major chlorine spill in Squamish is minimal (Schultz International, 1979). The worst situation would be the rupture of a storage tank. Only ten such ruptures have been recorded since 1917, in North America and only one after 1953 (Harris, 1978).

Transportation accidents usually occur at a location other than the manufacturing facility. Ten rail accidents involving major chlorine releases occurred in North America between 1970 and 1977, resulting in eleven fatalities.

Loading and unloading operations result in the majority of chlorine releases. There were five such incidents in North America in which large quantities of chlorine were released between 1970 and 1977.

6.3 Pesticide Use

Information concerning pesticide utilization in the Squamish area for 1978 and 1979, as documented in Pesticide Control Act Applications (Department of Fisheries and Oceans, Habitat Protection Division unpublished records) is presented in Table 18.

In 1974-75 the Federal Environmental Protection Service and the B.C. Fish and Wildlife Branch undertook a program to evaluate non-target contamination during aerial application of herbicides. An area near Squamish was included in this study, and is indicated in Figure 23. A seven hectare area of Weldwood Tree Farm Licence #38, between mile 33 and 34 on the main logging road from Squamish, was monitored during and after helicopter application of iso-octyl esters of 2,4-D and 2,4,5-T. Negligible water contamination of an adjacent creek was reported. However, it has been suggested that herbicide residue detected in the forest litter twelve weeks after application (see Table 19) may have entered the aquatic environment during periods of heavy rainfall in the fall or winter. This is not typically thought to be an important mechanism for stream contamination (Wilson and Wan, 1975).

6.4 Recommendation

In view of the quantities of chemicals shipped into and out of the area, a more complete review of their nature and quantity should be conducted. A contingency plan protecting both the public and the environment should be formulated.

VII Ambient Air Quality

7. AMBIENT AIR QUALITY

Air quality data for the Squamish area date back to 1972. Total dustfall, suspended particulates and sulphation rates were measured at three sites (S-1, S-2, S-3; Figure 24) from the summer of 1972 to the summer of 1974 by the Waste Management Branch. These data are summarized in Tables 20, 21 and 22 respectively for the three parameters. Total dustfall was within residential area objectives between 78 percent and 100 percent of the time, depending on the station. Total suspended particulates exceeded maximum Federal levels in less than 1 percent to 16 percent of the samples, depending on the site. However, haze has been mentioned by the public as a problem at Squamish. The potential source most often mentioned is the Woodfibre pulpmill. Since this problem evidently relates to visibility rather than to health, the best way to assess the problem would be to use an instrument such as an integrating nephelometer. This instrument measures the light scattering due to particles in the air. It is recommended that a one year study be undertaken to assess the degree and source of the problem.

The Waste Management Branch measured chlorine levels in ambient air from November, 1972 to May, 1974 at the Squamish School Board, at the Health Unit Office (S-4; EQUIS NO. 0310080) from August, 1974 to November, 1978, and then relocated the latter station to the Provincial Building (also called S-4 in this report, EQUIS NO. 0310172) from November, 1978 to date. Station locations are shown in Figure 24. Data from 1972 to 1974 are summarized in Table 23; the more recent data are presently being collated by the Waste Management Branch. All samples were within a Pollution Control Board Objective for Forest Products Industries.

Mercury was monitored by the Waste Management Branch at the Squamish Health Unit (S-4; EQUIS NO. 0310080) from August, 1974 to November, 1978, and at the Provincial Government Building (also called S-4; EQUIS NO. 0310172) from November, 1978 to date. In addition, FMC monitored mercury in the cell area (S-5) and at a site on Pemberton Street (S-6). Stations are shown in Figure 24 and data summarized in Table 23. Except within the cell area of the plant, concentrations were less than objectives which had been set for the Mining Industry by the Pollution Control Board.

A report on air pollution potential in Howe Sound (Coligado and Wilson,

1979) discussed the meteorology of the area utilizing Atmospheric Environment Service data. With respect to potential industrial development in Howe Sound, they concluded:

> "Air pollution potential in the southwest coast region is high, and the summer situation in the Howe Sound are is potentially serious. The local topography and marine effects produce a unique atmospheric situation which deserves further attention if industrial development proceeds. The data available, together with some understanding of the atmospheric processes involved, suggest that the most appropriate location for a pollution source (if one is to exist) is in the Port Mellon to Gibsons Landing area. However, it is to be emphasized that this conclusion should be considered tentative since wind patterns on the western side of the Sound are unknown. In particular, there are factors known to be producing local temperature inversions in the Sound which should increase the air pollution potential in comparison to that for the coastal region as a whole."

They recommend that a one year study of temperature inversions, winds and air quality be undertaken in areas of the Sound designated for industrial use. This has not yet been totally implemented, however the Air Studies Branch of the Ministry of Environment is carrying out a one year study of winds at Langdale.

Work carried out during the course of the study has been reported in Chapter 2.

VIII Riverine Water Quality

8. RIVERINE WATER QUALITY

8.1 Presentation and Discussion of Data

Water samples from the Squamish River, its major tributaries (Cheakamus and Mamquam Rivers), and the Stawamus River have been collected since 1972 by the Waste Management Branch and the Inland Waters Directorate. The results of sample analyses to January 1980 have been summarized in Table 24. Table 25 lists a number of published receiving water criteria for aquatic life, and drinking water objectives.

The locations of the sampling sites on these rivers are shown in Figure 25. Municipal and industrial discharges to these rivers include: Northair Mines (PE 4106) tailings supernatant and mine waters and the Whistler STP (PE 1452), which discharge upstream from sampling site 0300095 into the Cheakamus River; and the Mamquam STP (PE 1511) which discharges downstream from sampling site 0300093 into the Squamish River.

Parameters for which a sufficient data base existed were compared between sampling sites using a random pairs statistical test. This test compares the differences in magnitude and sign between pairs of values, and determines the probability of the observed differences occurring more often than by chance. A detailed explanation of this test is presented in Seigul (1956). The results of these tests are summarized in Table 26, and are discussed in the following sections. The comparisons between sampling stations noted in the table were performed in groupings of a maximum of twelve dates, beginning with the most recent data. This procedure has lead to more than one comparison having been made for some parameters at some stations. Where comparisons have differed, both results have been presented. Observed differences in earlier data may have resulted from fewer than twelve data pairs having been compared.

Data for the period of record were grouped according to the month during which the data were generated for all sampling sites on the Mamquam, Stawamus and Squamish rivers. The temperal trend analysis was performed for all analyses. Alkalinity, hardness, magnesium, phosphorus, silica, and suspended solids showed seasonal patterns.

8.1.1 General Ions and Field Parameters

The data in Table 24 indicate that the values for total magnesium, dissolved phosphate, sulphate, and dissolved oxygen vary little among the five sampling stations. The median values for these parameters, excluding dissolved oxygen, were lower than the median values listed for all monitored B.C. streams. The median dissolved oxygen values were similar to the median values for B.C. streams. With median values for dissolved oxygen ranging from 8.5 to 11.8 mg/L, it is probable that dissolved oxygen values were always near saturation. The values were within the criteria suggested as safe for anadromous fish fry (Davis, 1975; see Table 25).

The data presented in Table 27 indicated that lower concentrations of magnesium were recorded during freshet (June to August) than during low flow (December to February), probably due to the dilution of snow melt. Conversely, higher total phosphorus values were recorded during freshet period than during low flow, probably due to scouring of sediments. These trends were based upon limited data, particularly during the low flow period.

The values of dissolved calcium, dissolved magnesium, total alkalinity, hardness, pH, and specific conductance varied significantly between the sites according to the random pairs statistic. The Cheakamus River (0300095) had the highest values, followed in order by the Mamquam River (0300093), downstream Squamish River (0300094), upstream Squamish River (0300194), and the Stawamus River (0300092). The higher values at the downstream Squamish River site (0300094), when compared to the upstream Squamish River site (0300194), were likely the result of the mixing of Cheakamus River (0300095) waters which had the highest values for these parameters. The median and maximum values for these parameters were well below the median values for all monitored B.C. streams. The water at all sites can be classified as "very soft" water (hardness less than 30 mg/L). Certain contaminants are more toxic in soft water (Inland Waters Directorate, 1972). The low values for hardness, total alkalinity, and total calcium result in a poor inherent buffering capacity to both acidic and alkaline solutions (Appendix A). The Stawamus River appears to be the least adequately buffered river studied, since the lowest values for the above parameters were recorded at station 0300092.

The data presented in Table 27 indicated that alkalinity and hardness values were lower during freshet than during low flow. This suggests a better buffering capacity during low flows. These trends were based upon limited numbers of data, particularly in the December to February period.

Chloride levels varied significantly between the sites, with the highest value recorded in the Cheakamus River. Lesser values were recorded at the downstream Squamish River site, the upstream Squamish River site, the Mamquam River site, and the Stawamus River site. The elevated values at the downstream Squamish River site were believed to be the result of the dilution of high chloride Cheakamus River waters. The median values for chloride were slightly greater than the median value for all monitored B.C. streams, but were well within published water quality criteria for aquatic life and drinking water supplies (Table 25).

8.1.2 Colour and Particulate Matter

True colour and turbidity values were very similar among the various sites, and were both within acceptable ranges for water quality criteria. The values for true colour ranged from <5 to 10, except for one value which was recorded at the upstream Squamish site 0300194. The median value for all sites was 5 relative units, the same as the median value for all B.C streams.

Turbidity values showed no significant difference between the Squamish River sites or either of its major tributaries (Cheakamus and Mamquam Rivers). However, turbidity values in the Stawamus River were slightly lower than for values at the other sampling sites. The median turbidity values were similar to the median value of 2.2 Jackson Turbidity Units (JTU) for all monitored B.C. streams.

Values for non-filterable residue (suspended solids) were highest in the mainstem of the Squamish River. Values were slightly higher at the upstream station 0300194 relative to the downstream station 0300094. The Cheakamus, Stawamus and Mamquam rivers had lower median values than those in the Squamish.

The results of the random pairs analysis indicated that the Cheakamus River had significantly lower suspended solids values than were recorded at

the Squamish River sites, but significantly higher values when compared to the Mamquam and Stawamus rivers. The values for suspended solids at the mainstem Squamish sites exceeded the median value of 6 mg/L recorded for all monitored B.C. streams. However, the median values for the Cheakamus, Mamquam and Stawamus sites were lower than the median value for all monitored B.C. streams.

The data for suspended solids have been summarized in Table 27. The data generally indicate higher suspended solids values during freshet when compared to the low flow period. This is due to the erosion of bank material and bottom sediments as river flows increase during freshet. However, the trend analysis was based upon a very limited data base, particularly for the low flow period.

8.1.3 Nutrients

There appears to be no significant difference between sites for most of the nitrogen-based nutrients including ammonia, nitrate/nitrite, organic nitrogen, and Kjeldahl nitrogen among the five sampling sites (Table 26). However, a significant difference did exist for nitrate values between most sites, the exception being the upstream Squamish River site in comparison with the downstream Squamish River site. Other exceptions included ammonia, which was significantly higher in the Cheakamus River than the downstream Squamish River site; organic nitrogen, which was significantly higher in the Stawamus River than in the Mamquam River; and Kjeldahl nitrogen, which was higher in the upstream Squamish River site than in the Cheakamus River between 1972 and 1975.

Median values for the inorganic nitrogen forms (NH_4, NO_2, and NO_3) were comparible to the median values for monitored B.C. streams. The median values for Kjeldahl nitrogen were approximately one-tenth the median for monitored B.C. streams.

Ammonia values are reported as the sum of the dissociated (NH_4^+) and undissociated (NH_3) forms. In aqueous solutions the two forms of ammonia are in equilibrium with each other, as illustrated in the following equation.

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

This equilibrium is mainly a function of the pH, and to a lesser extent salinity

and temperature. Free or undissociated ammonia (NH_3) is the form of ammonia primarily toxic to aquatic life. Levels in excess of 0.02 mg/L-NH_3 are toxic to aquatic life (EPA 1976). With the equilibrium equations presented in Clark and Drinnan (in press) the concentration of undissociated ammonia can be estimated if the pH, temperature, and salinity are known.

Table 28 presents the estimated concentrations of undissociated ammonia for a range of total ammonia, pH and temperature. Salinity in these calculations is assumed to be zero since this represents the worst-case situation.

The rivers entering the study area are low in levels of total ammonia (N), with a range of medians from 0.007 to 0.01 mg/L (maximum value 0.17 mg/L). Median values for pH ranged from 6.9 to 7.3 (maximum value 7.6), and temperatures ranging to a maximum recorded value of 16.8^{o}C. Even at the maximum values for these parameters, the maximum concentration of undissociated ammonia (N) assuming no salinity would have been approximately .002 mg/L, well below the water quality criterion of 0.02 mg/L-NH_3 or 0.016 mg/L NH_3-N. Thus ammonia toxicity in these rivers has not been a problem.

It can be seen that only at pH values of 8.0 or greater do the undissociated ammonia levels have the potential of exceeding water quality criteria. These data suggest that strongly alkaline discharges should be avoided to minimize the potential of ammonia toxicity problems. As noted in Appendix A, these river waters are very poorly buffered against the discharge of strong basic effluents.

The median values for ortho-phosphate and total phosphate were very similar to the median values for all monitored B.C. streams, while median values for silica were slightly higher than the median for all monitored B.C. streams. Insufficient data existed to statistically compare silica values at the five sites. Significant differences existed after 1975 for ortho-phosphate between the Cheakamus and Stawamus rivers, the Cheakamus and Mamquam rivers, and the Cheakamus and downstream Squamish River sites. These differences did not exist between 1974 and 1975. Total phosphate values were found to be significantly different between the Cheakamus and Stawamus rivers, the downstream Squamish River site and the Stawamus River, and the Cheakamus River and both Squamish River sites in the period from 1972 to 1974.

Data for silica are summarized in Table 27. The data were limited. No trend was indicated.

Loading estimates for nutrients in the Squamish River estuary were calculated by Kleiber and Erlebach (1977) for the period March to December 1974. These calculations showed that the Squamish River contributed 984 tonnes of phosphorus, 296 tonnes of nitrogen, and 24 400 tonnes of silica; the Mamquam River contributed 38 tonnes of phosphorus, 35 tonnes of nitrogen and 6 900 tonnes of silica; the Cheakamus River contributed 39 tonnes of phosphorus, 41 tonnes of nitrogen, and 6 900 tonnes of silica; for a total loading of 1 061 tonnes of phosphorus, 372 tonnes of nitrogen and 38 200 tonnes of silica. By comparison, the total amounts present in Howe Sound were estimated to be 200 tonnes phosphorus, 800 tonnes nitrogen and 4 000 tonnes silica.

Levels of nitrogen and phosphorus in the Stawamus River were well within the Canadian Drinking Water Objectives (1969). Total phosphorus and total nitrogen in the Squamish River were at concentrations similar to those typically found in low to moderately productive rivers, 0.002-0.23 mg/L and 0.05-1.1 mg/L, for phosphorus and nitrogen respectively (Vollenwider, 1971), although total phosphorus values of less than 0.01 mg/L have been implicated in an increase of benthic algae in the Thompson River (Olan, 1975).

8.1.4 Trace Metals and Miscellaneous Toxicants

A number of metals were measured in the Cheakamus, Mamquam, Stawamus, and Squamish rivers. These included arsenic, boron, chromium, copper, cyanide, lead, manganese, mercury, molybdenum, nickel, and zinc. The respective detection limits will not be reproduced here, but are indicated in Table 24 as the minimum recorded values at several of the sampling stations. The median values for these parameters were similar to the median values for all monitored B.C. streams.

Maximum recorded values for total copper, total manganese, and total zinc exceeded several water quality criteria (Table 25). Few data were available for the dissolved fraction of these metals. It is the dissolved metals which are available and therefore toxic to aquatic organisms. Dissolved metal data which were available met the water quality criteria for aquatic life.

Total iron was the only parameter for which either sufficient data pairs were available to perform the random pairs test or for which there was a significant difference between sites. Total iron values at the downstream Squamish River site were higher than values in the Mamquam River. Total iron values were also higher at the upstream Squamish River site than values in the Cheakamus River. Median values for total iron at both Squamish River sites were higher than the median value for all monitored B.C. streams.

Dissolved iron values were similar at all sites. The median values were similar to the median value for all monitored B.C. streams.

Tannin and lignin values were recorded only in the Mamquam River. The median value of <0.005 mg/L (detection limit) was less than the median value of 0.006 mg/L recorded for all monitored B.C. streams. Phenolic compounds were measured in the Stawamus River on one occasion. The recorded value was 0.002 mg/L (detection limit).

8.1.5 Bacteriological Quality

Few data for fecal or total coliform were available for the sampling sites. Data which were available were collected between 1972 and 1979. Due to the inherent variability of coliform results, it was difficult to assess these data.

The geometric means for fecal coliform ranged between 8 and 15 MPN/100 mL, while the geometric means for total coliform ranged between 14 and 71 MPN/100 mL at all sites. The random pairs analysis indicated no significant difference between bacteriological levels at most of the sites.

The site on the Stawamus River (0300092) is located 3 miles downstream from the Squamish District Waterworks intake pipe. If coliform data for the Stawamus site are representative of the water at the intake pipe, the water is within the acceptable drinking water criteria for fecal coliform (only one value exceeded 100 MPN/100 mL) and within the maximum permissible limit for total coliform (two values exceeded 1 000 MPN/100 mL), but would require disinfection.

The District of Squamish chlorinates and fluoridates its domestic water. Sixty samples from the domestic system, collected by the B.C. Ministry of Health on January 30, 1980, were all coliform free (Wilson, personal communication).

Elevated levels of fecal coliform were found downstream from the Mamquam River station in the zone of influence of the Mamquam STP outfall.

8.2 Summary

Water quality data were examined for two sampling sites on the Squamish River, as well as for sites on the Mamquam River, the Stawamus River, and the Cheakamus River.

Most of the parameters reported at the five stations met the water quality criteria for the propagation and maintenance of aquatic life (Table 25). This was not true for the maximum recorded values for total copper, total manganese, and total zinc. It has not been established whether these elevated metal levels pose a threat to aquatic resources, as sufficient data on existing concentrations of the dissolved (biologically available) fraction of these metals are not available. The median reported values for most parameters were equal to or lower than the median values reported for all monitored B.C. streams, except for dissolved oxygen and suspended solids.

The influence of freshet was noted on the reported concentrations of many parameters at the five stations. These parameters included total phosphorus and suspended solids, which were higher during freshet. Lower values of alkalinity, hardness, and magnesium were found during freshet. It is believed the higher phosphorus and suspended solids values reported during freshet resulted from the resuspension of bottom sediments and erosion of bank material.

Water sampling by government agencies has typically coincided with the freshet period at the five sampling stations. This has resulted in a paucity of data related to low flow conditions. This monitoring data gap should be filled in the future for all sampling stations.

The water at the five stations sampled was found to be poorly buffered

against the discharge of strong basic solutions. Alkalinity values were lower during freshet than during low flow.

Ammonia values were low. Ammonia toxicity will only become a problem should temperature and/or alkalinity be elevated simultaneously. This is unlikely.

IX Estuarine Water Quality

9. ESTUARINE WATER QUALITY

9.1 Presentation and Discussion of the Data

Numerous investigators have measured water chemistry parameters in the deeper estuarine waters and in the inner estuary (central basin and deltas) to define the characteristics of the estuary and to measure changes in habitat and productivity following construction of the training dyke (Giovando, 1972; Bell, 1973; Cliff and Stockner, 1972; Buchanan and Stockner, 1976; Buckley and Pond, 1976; Levings et al., 1976; Pomeroy, 1977; Stockner et al., 1977; Levings, 1980 and Levings in Freeland et al., 1980). The major water chemistry parameters measured were salinity, temperature, dissolved oxygen and nutrients. The sampling locations are shown in Figure 27.

Alkalinity, trace metal, and organic contaminant data are also discussed in sections which follow.

9.1.1 Salinity

Pomeroy and Stockner (1976) compared the salinity values at the undisturbed west delta to those at the east delta (inside the dyke). They found higher surface salinities at the east delta than the west delta during river freshet and winter (3 to 27 parts per thousand (ppt) from freshet to winter at the east delta compared to 1 to 8 ppt from winter to freshet at the west delta). They also observed that the vertical salinity profiles in the upper 2 metres showed lower salinity and less vertical gradient at the east than at the west. These differences were attributed to reduced freshwater input to the east delta due to the river diversion, which provides freshwater access through only two culverts (Section 3.1) in the dyke. Similar results were shown by Levings (1980) who found higher surface salinities at the central basin and east delta than at the Squamish River (see Figure 28). Levings (1980) suggested that the vertical salinity distributions were little affected by the limited freshwater flow through the culverts.

In the vicinity of the sill (Figure 9), Buckley and Pond (1976) reported surface salinity values of approximately 4 ppt while values at 20 metres depth were 29 ppt. The halocline (depth range of rapid salinity change) is

present throughout the year. The depth of the halocline changes with river flow, becoming more shallow in winter when river runoff is low, and deeper and more defined during freshet in May and June.

Within the surface water layer, in Upper Howe Sound, there is generally good mixing due to wind action (Giovando, 1972). However, some stratification can occur in these surface waters as a result of solar insolation (Stockner et al.). This change in temperature produces a shallow minor density gradient (pynocline) which can occur concurrently with the deeper major halocline caused by the freshwater lens. The pynocline results mainly from the vertical salinity gradient which results from freshwater runoff mixing partially with the upper layer of sea water.

The salinity measurements recorded at eight sampling locations in Mamquam Blind Channel are shown in Figure 30. These measurements were obtained using a Hydrolab multiprobe sensing unit during low and high tides, between June 24 and 26, 1980. During low tide, the surface salinities ranged from 1.96 to 6.5 ppt. The lowest surface salinity values were recorded in the vicinity of the Stawamus River. The highest values were recorded at the two stations near the head of the channel. During high tide, the surface salinities were 4.3 ppt in the vicinity of the Stawamus River and as high as 8.26 ppt at other stations. These values correspond to surface salinity concentrations of about 6 ppt reported by Levings et al. (1976) for sampling undertaken in June, 1973. Levings et al. (1976) found significantly higher surface salinities in the winter months, corresponding to reduced river outflow.

The presence of a salinity gradient in Mamquam Blind Channel was apparent particularily during high tide. Saline waters were found at all of the stations during this tide, suggesting intrusion of Howe Sound water into Mamquam Blind Channel to the highway bridge (Figure 31). However, freshening of the channel both upstream and downstream from the Stawamus River confluence was suggested during low tide. A report suggested that the channel appeared well flushed, and that appreciable dissolved oxygen values were present.

9.1.2 Temperature

During much of the year, the Squamish River consists of melt water from snow pack at high elevations. This melt water decreases the river temperature to below that of the surface waters of Howe Sound. Stockner et al. (1977) found progressively lower surface water temperatures at up-inlet stations (means of 8.8 to 11.7° C in 1973 and 3 to 10.5° C in 1974, Table 29) which they attributed to the increased influence of the river. Levings et al., 1976, found increased water temperatures with depth at the mouth of the river. This was attributed to the presence of a warmer saltwater wedge underlying the cooler riverine waters. This temperature difference was less pronounced in summer, due to warming of the river water.

One consequence of the temperature difference between the saltwater and river water is the existence of higher water temperatures in the central basin and east delta (primarily saline) than in the Squamish River and west delta. This is a potential factor influencing the nature of the aquatic communities present.

The temperature measurements from vertical profiles taken at eight locations in Mamquam Channel (Figure 31) are given in Table 30. The values ranged from 9.8° C to 13.3° C with the slightly higher temperatures observed during high tide. The temperature of the drainage entering by way of the culverts, was 10.5° C.

9.1.3 Dissolved Oxygen

Levings et al. (1976) tabulated dissolved oxygen data, collected in 1974 and 1975, for the east delta, the west delta, the central basin, and Mamquam Blind Channel. Our review of the data indicated that the levels were generally high (maximum 16.41 mg/L or 170% saturation). Higher concentrations were found in the waters of the Squamish River, although oxygen saturation values remained comparable. There was no evidence of stagnation indicated by the dissolved oxygen values. However, values of 1 to 2 mg/L were recorded on one occasion (December 18, 1974), in the saline water of the salt wedge along the seaward edge of the central basin and Mamquam Blind Channel.

Stockner et al. (1977) reported dissolved oxygen values at depths from 0 to 20 metres during 1973 and 1974. The sampling locations extended up the inlet (Figure 27). Conversion of these values to percent saturation resulted in mean values for all the stations from 67.4% to 77.6% in 1973, and from 61.9% to 75.3% in 1974. Over the two-year period, Stockner et al. (1977) found seasonal changes at depths from 0 to 5 metres, with higher values corresponding to greatest phytoplankton biomass.

Low dissolved oxygen values have been recorded (Figure 32) on several occasions in the bottom waters at depths from 200 to 250 metres near the sill (Levings in Freeland et al., 1980). It is believed these low values were due to the slow rate of bottom water renewal which results from the presence of the sill (Chapter 4). The low values (less than 1.5 mg/L) were present during the autumn months of 1977 and 1978. This suggests that there was little water renewal during those periods. Progressive oxygen depletion in the deep water inside the sill of Howe Sound may be a regular occurrence, as it is in some other fjords. The apparent susceptibility to oxygen depletion of bottom waters behind the sill requires that care should be exercised in regulating industries which might discharge high oxygen demanding effluents to deep waters in this area.

The dissolved oxygen data (two surveys - June 1980) for Mamquam Blind Channel are summarized in Table 30. During both high and low tides, values decreased with depth. The lowest percent saturation values during low tide were 67.4% and 67.7% at the bottom of sites 3 and 4, respectively. During high tide, the lowest percent saturation values (73.7% and 63.7%) were also recorded at sites 3 and 4. The percent saturation values (67.4 to 92.0% during low tide and 63.7 to 97.8% during high tide) were slightly greater than the range of values found by Stockner et al. (1977) for the inlet and delta. This suggests that there was no apparent serious oxygen depletion in Mamquam Blind Channel at that time.

9.1.4 Nutrients

Studies by Cliff and Stockner (1972), Buchanan and Stockner (1976), Stockner et al. (1977) and Pomeroy (1977) provided nutrient data for phosphate, silica, and nitrate in the surface waters of the deeper estuarine waters and the delta areas. The sampling locations are indicated in Figures 27 and 33, and the conclusions of the studies are summarized below.

In the deeper estuarine waters and outer delta area, Stockner et al. (1977) found uniform concentrations of phosphate, silica and nitrate to depths of 20 metres at ten sampling locations. Relatively high values of phosphate-P (mean values ranging from 0.032 to 0.062 mg/L in 1973, and from 0.046 to 0.060 mg/L in 1974) and silica-Si (mean values ranging from 0.91 to 1.08 mg/L in 1973, and from 0.87 to 1.33 mg/L in 1974) were present throughout the year, although some minor decreases were observed in late spring and summer. Nitrate-N values showed definite seasonal trends, with high values in winter (0.388 mg/L at station 3, Figure 27) and greatly reduced values just preceding the spring phytoplankton bloom (less than 0.02 mg/L at stations 3). The nitrate values remained low during the summer, particularly at deeper water sites. This was attributed to little mixing of the waters and thus little replenishment from the deeper waters following consumptive uptake by phytoplankton near the surface in the spring. Similar results were found for nitrate by Buchanan and Stockner (1976).

In the delta areas, Cliff and Stockner (1972) found that the phosphate and nitrate values in the surface waters were relatively high (Table 31). They speculated that these nutrients could be continually brought to the surface by entrainment and upwelling of nutrients from the rich bottom waters. This could be due to greater mixing in the delta area, than in the deeper estuarine waters, in part owing to greater turbulence caused by shallowness and narrowness and to stronger winds caused by wind funnelling (see Section 2.4).

Pomeroy (1977), in data recorded in Table 32, reported higher nutrient levels in Snag and Pile Creeks (Figure 33) than in the surrounding waters, although the seasonal patterns were similar in the creeks and surrounding waters. The highest levels of nitrate and phosphate were observed in January. Dif-

ferences were also associated with tidal cycles, the concentrations being greatest at ebb tide.

Theoretical concentrations for undissociated ammonia at a salinity of 20 ppt (comparable to that reported for surface waters of Howe Sound, Gough, unpublished) and for a range of total ammonia, temperature, and pH values, are summarized in Table 33. The calculated range of total ammonia values corresponds closely to those reported for tidal creeks within the Central Basin (Table 32). The pH in the estuary rarely exceeds 7.9, and is usually in a range from 6.9 to 7.7.

The possibility of increasing ammonia toxicities in the estuary by increasing the pH in the estuary is not considered to be a significant problem, since the estuary waters are better buffered than riverine waters (Section 9.1.5). However, areas of the estuary with low salinity values (high concentration of riverine waters), or areas with poor water exchange, should be avoided when discharging basic pH, high ammonia (greater than 4 mg/L) effluents.

9.1.5 pH and Alkalinity

Pomeroy (1977) reported pH data (Table 32) for samples collected in the Central Delta (Figure 33) at various stages of the tidal cycle during 1974 and 1975. The pH ranged from 6.93 in July to 7.7 in April. The pH in Snag and Pile Creeks was 0.1 to 0.2 pH units lower than the surrounding waters, with little variation observed between the creeks.

The limited alkalinity data for surface waters adjacent to the delta suggested that these surface waters are poorly buffered and thus susceptible to changes in pH. The Squamish River Estuary Management Study Air and Water Quality Work Group identified the need for additional data. This was collected in September 1980, and is reported in detail in Appendix A, with station identification in Figure 34.

In general it was determined that the buffering capacity to both acids and bases increased with an increase in water salinity. The buffering capacity

of all surface samples of estuary water to alkaline discharges is comparable. The buffering capacities of riverine waters to acids was poor. The pH values in Mamquam Blind Channel were generally found to be neutral or slightly acidic (Table 30).

9.1.6 Mercury

Limited information is published concerning levels of mercury and other metals in Howe Sound waters. Thompson and McComas (1973) measured dissolved and particulate mercury in 1972 near FMC, Britannia Beach, and Gambier Island (Table 34). Surface waters near Gambier Island had the highest mercury levels (0.234 µg/L). These data indicate total mercury levels in excess of the Environmental Protection Agency (U.S.) (1972) criterion of 0.10 µg/L for the protection of marine aquatic life. However, the data were analyzed in 1972 when analytical procedures were not refined and values reported may therefore be higher than actual values (Thompson, personal communication).

Thompson and McComas (1973) and Beak Consultants (1978b) discussed the effects of the FMC discharge upon the water chemistry of Howe Sound. Both reports concluded that the major impact of the FMC discharge was upon the bottom sediments as opposed to water. Further discussion is contained in Section 10.1.3. Thompson and McComas (1973) reported no apparent relationship between dissolved mercury levels in Howe Sound and the presence of the effluent discharge. They did however, note elevated values of mercury in the particulate fraction of the water near FMC. Values adjacent to the FMC outfall were as high as 9.6 µg/gm on the surface while at Port Mellon, the highest value was 2.4 µg/gm, at a depth of 88 metres. Recent analyses of dissolved mercury concentrations at the surface and at 20 metres depth off Woodfibre, by Beak Consultants (1978 b), indicate that values are essentially at background concentrations.

Water quality data from Howe Sound have been collected periodically (4 to 6 times a year) since 1972 (Gough, unpublished). At the station nearest the estuary (coinciding with Stockner et al., 1977 station 8, Figure 27 opposite Woodfibre), mercury levels were generally at or below the detection limit of 0.05 µg/L (16 of 22 values), with a maximum value of 0.18 µg/L having been recorded in June 1973.

Water samples were collected on June 13, 1980, from the marsh on FMC property, and from Cattermole Creek. The mercury and total organic carbon data for the samples are presented in Table 34. The sampling locations are indicated in Figure 35. Mercury concentrations in the marsh waters ranged from 0.27 µg/L to 2.62 µg/L. This range corresponded to the range (<0.1 µg/L to 2.8 µg/L) reported for one site (approximately station 6) sampled between January 1975 and August 1978 by Beak Consultants Ltd. (1978 b). The mercury values in the marsh exceeded mercury concentrations in the Squamish River (<0.05 µg/L), suggesting possible infiltration from the settling pond and sludge disposal areas.

There was no apparent correlation between the mercury values and total organic carbon values in the samples. However, the high total organic carbon values due to eutrophic habitat may mask any relationship.

The association of water-borne mercury with particulates and subsequent particulate precipitation is suggested by elevated levels in the marsh sediment (Section 10.1.3). Mercury levels in the marsh waters exceeded the Environmental Protection Agency (U.S.) (1972) for the protection of aquatic life (recommended maximum of 0.2 µg/L in freshwater, not listed in Table 25, and 0.1 µg/L in marine water). Aquatic insects were observed in marsh waters suggesting that the waters are not acutely toxic to all aquatic organisms.

The mean mercury value in Cattermole Creek was 0.46 µg/L (range 0.13 µg/L to 1.15 µg/L). These values were slightly lower than in the adjacent marsh, but higher than values in the Squamish River (<0.05 µg/L). The mercury may originate from two sources; seepage from the marsh, or from intrusion of the effluent during high tide.

Additional monitoring of mercury levels in the marsh and Cattermole Creek is not recommended at this time. Monitoring of mercury levels in the waters in Howe Sound adjacent to the abandoned settling pond should continue, to assess the effectiveness of the measures to reduce mercury leaching from the abandoned pond.

9.1.7 Other Trace Metals

Samples from Howe Sound waters have been collected periodically (4 to 6 times a year) since 1972 for metal analyses (Gough, unpublished). Copper and zinc values were low (the median concentrations were 0.003 mg/L and 0.007 mg/L, respectively), with maximum recorded values of 0.006 mg/L for copper and 0.03 mg/L for zinc. Both copper and zinc levels appeared to be higher at sites nearest Britannia Mine Site. These results are similar to data reported by Levings et al. (1976) which indicated that dissolved copper levels in the water column within one kilometre of Britannia Creek were 3 to 4 times higher than at stations further distant.

Concentrations of other trace metals measured in samples collected at Howe Sound stations were also generally very low (Gough, unpublished). Median concentrations at a sampling station which coincided with station 8 used by Stockner et al., (1977) (Figure 27), were as follows: arsenic - 0.005 mg/L; total cadmium - 0.0005 mg/L; total chromium - 0.005 mg/L; total iron - 0.19 mg/L; total lead - 0.001 mg/L; total manganese - 0.003 mg/L; and total nickel - 0.01 mg/L; all below published water criteria. No pattern was noted for these metals in Howe Sound.

9.1.8 Organic Contaminants

The only available data on organic contaminants in Howe Sound waters was a sample collected in November 1978, near Weldwood of Canada Empire Lumber in Mamquam Channel (Department of Environment, 1979). The sample contained 5.2 µg/L tetrachlorophenol, 2.4 µg/L pentachlorophenol, 0.020 µg/L pentachloroanisole, and a trace of pentachlorobenzene. Trichlorophenol, hexachlorophenol and tetrachlorobenzene were below the detection limits (approximately 1.25 µg/L, 1.25 µg/L, 0.125 µg/L respectively.

9.2 Summary

Salinity values in surface waters of the Squamish delta were found to be higher in the east delta than in the west delta, while vertical salinity profiles showed less marked salinity gradient and lower salinity in the upper two

metres at the east delta than the west. This has been attributed to reduced freshwater input to the east delta as a result of the design of the flood control dyke currently in place. The Squamish River and Howe Sound approximate a classic river/fjord estuary system with a significant freshwater input at the head of the fjord and restricted seawater input due to the presence of a sill. In deeper estuarine waters, salinity stratification occurs as Squamish River input spreads out over the seawater in the form of a freshwater lens. Some mixing does occur at the freshwater/seawater interface as the lens moves down the inlet. The depth of the halocline varies seasonally. Mamquam Blind Channel appears to be relatively well flushed, with intrusion of estuary water at high tide. Salinity values in Mamquam Blind Channel were higher during winter, due to lowered freshwater input.

The temperature of Squamish River water is lower than the surface waters of Howe Sound during most of the year. The temperature of the water increases with depth due to intrusion of the higher temperature saltwater wedge beneath the freshwater outflow. This temperature profile was less pronounced during warmer weather. Warmer water temperatures were recorded in the central basin and east delta than in the Squamish River or the west delta. This can potentially influence local aquatic communities present.

High dissolved oxygen values were recorded in the east and west deltas, and the central basin in 1974 and 1975. Higher dissolved oxygen values were recorded in the Squamish River. There were no areas of consistent oxygen depletion in the above areas nor further down inlet at stations sampled in 1973 or 1974. However, low dissolved oxygen values were recorded in deep waters of Howe Sound north of the sill in the autumn of 1977 and 1978. This was attributed to minimal water renewal at depth in this area. It is recommended that high oxygen demanding wastes not be discharged such that they might reach this area. Seasonal changes in dissolved oxygen values occurred in waters of Howe Sound at depths to 5 metres, with the highest dissolved oxygen values corresponding to the greatest phytoplankton biomass. No apparent oxygen depletion was noted in Mamquam Blind Channel during 1980.

There are uniform phosphorus, silica, and nitrate values in the deep estuary waters and the outer delta areas. In the inner delta areas, it is

believed that entrainment and upwelling of deeper and more saline seawater resulted in elevated levels of phosphorus and nitrate in surface waters. Nitrate values showed definite seasonal trends, with high winter values and greatly reduced values just prior to the spring phytoplankton bloom. Nitrate values remained low during the summer due to little upward mixing of deeper water layers.

It is probable that ammonia values in the estuary are not a problem at the present pH values. However, areas of the estuary with low salinity, or areas with poor water exchange, should be avoided as disposal areas for alkaline discharges. The effect of the effluent plume from the Central STP on ammonia values in the estuary at low tide should be assessed.

The buffering capacity of estuary water increased with salinity, and was equally buffered for both acidic and alkaline discharges. The buffering capacity of riverine waters to acidic discharges is poor.

Studies have concluded that the major impact of the FMC discharge was upon the bottom sediments as opposed to water. Low values of metals other than mercury were recorded in Howe Sound. Chlorinated organic contaminants were recorded in Mamquam Blind Channel, adjacent to Empire Lumber.

X Sediment Quality

10. SEDIMENT QUALITY

10.1 Presentation and Discussion of Data

10.1.1 Sediment Size Distributions

There is a marked decrease in the content of metals in sediments as the grain size increases (V. Förstner, 1976). The grain size of sediments and the carbon content have a covariant relationship (Crecelius et al., 1975). Organic matter is believed to be the most important factor in controlling mercury levels in sediments (Crecelius et al., 1975 ; Lindberg et al., 1973). The ability of sediments to complex and retain metals in non-biologically available forms is important to the study when determining dredging effects and dredge spoil disposal methods.

Sediment samples were collected within the study area from Cattermole Creek and Mamquam Blind Channel. The sample locations are indicated in Figures 35 and 36. The sediment size data were obtained using a Tyler mesh sieve series on dry samples.

The data indicate that the median particle diameters varied widely in both Mamquam Blind Channel and Cattermole Creek. The fine sediments in Mamquam Blind Channel occurred in areas of intertidal waters, or where reduced current velocites were noted. The sediments in Mamquam Blind Channel were poorly sorted. There was no apparent pattern of sorting among sites. Sediments adjacent to the mouth of the Stawamus River were better sorted than sediments at most other sites.

Samples collected adjacent to the Weldwood Empire Lumber chip loading facilities were dark coloured, odorous, and contained considerable quantities of woodfibre.

The data for Cattermole Creek are summarized in Table 39. The smallest median particle diameters were noted along the west bank of the creek, adjacent to the salt marsh. Slightly larger median particle diameters were noted along the east bank of the creek, adjacent to the dykes. The largest median particle diameters were generally observed at mid-creek stations. Presumably, the fine

materials at these stations are washed out into the estuary by high current velocities during low tide.

10.1.2 Total Organic Carbon

Total organic carbon values were measured in sediments in the marsh on FMC property, in Mamquam Blind Channel and in Cattermole Creek. The data are included in Table 40.

The values were higher in Mamquam Blind Channel (range of values from 7.6 mg/g to 67 mg/g) than in the marsh on FMC property (range of values from 4.7 mg/g to 11 mg/g) or in Cattermole Creek (range of values from 0.5 mg/g to 3.3 mg/g). The highest values in the Mamquam Blind Channel were recorded at sites adjacent to log booming areas (Stations 14, 15, 16 and 17 in Figure 36) and adjacent to the Weldwood Empire Lumber wood chip loading facility. The sediments at these locations were dark in colour, odorous, and contained visible woodfibre particles.

Values of total organic carbon were relatively consistent in sediments at all stations, considering the spread of values found for the replicate samples from Station 3 in Mamquam Blind Channel. The highest values of total organic carbon in sediments from Cattermole Creek were found at sampling stations located on the west bank, where there are naturally occurring marine sediments.

10.1.3 Mercury

(a) Sediment Characteristics Affecting Mercury Levels

The concentration and form of mercury in sediments is determined by a number of factors (Mercury in the Canadian Environment by I.C. Sherbin, 1979 and Mercury in British Columbia and Yukon Environments by C. Garrett et al., in press). The following discussion is based largely on these two reports.

Elevated mercury concentrations are typically associated with fine

sediments, high in organic content. The capacity of such sediments to bind mercury decreases with relative oxidation. The potential danger posed by elevated mercury levels in sediments arises from the possibility that under certain environmental conditions, the conversion of mercury to its more mobile and toxic forms is promoted. The degree to which this conversion occurs depends upon such factors as the availability of methylating bacteria, the form and concentration in which the mercury was deposited, and such receiving environment characteristics as pH, redox potential, and oxygen concentration (Swiss et al., 1980).

Methylmercury (CH_3Hg^+) is considered to be the most toxic form of mercury and readily accumulates in aquatic organisms. The process by which it is formed from elemental mercury in the aquatic environment through bacterial action is known as methylation. The net result of methylation is either mono- or dimethylmercury. Mono-methylmercury has been shown to accumulate in living organisms. Although there is little experimental evidence concerning the fate of dimethylmercury, it is assumed that it is primarily released to the atmosphere. Sediments with low elemental mercury levels or high pH favour the formation of dimethylmercury. As elevated elemental mercury concentrations, or at low pH, monomethylmercury is typically formed. At pH values less than 5.6, dimethylmercury is unstable and is converted to monomethylmercury. Methylation can occur under aerobic and anaerobic conditions but is promoted in aerobic environments.

Demethylation of methylmercury can be accomplished by micro-organisms in sediments. This process may serve to maintain a control on methylmercury accumulation.

(b) Mercury Levels

A number of studies have been undertaken to investigate sediment concentrations of mercury in the study area (Beak Consultants on behalf of FMC, 1970-71, 1977; Thompson and McComas, 1972-73 and Thompson in 1976; Macdonald and Wong, 1977). Data from these studies are presented in Tables 40 to 49. Sampling locations are illustrated in Figures 39 to 42.

Surveys of northern Howe Sound and the Squamish estuary, by Thompson and McComas in 1972-73 and Thompson in 1976, revealed mercury deposits in the

sediment over a 1 550 hectare area near the FMC chlor-alkali plant (Thompson et al., 1980). Thompson et al., (1980) have estimated that about 450 kilograms of mercury exists in sediments adjacent to the chlor-alkali plant. Areas of highest levels (up to 1 µg/g) were found to the south and east of the plant for about two kilometres, and in the area off Watts Point and in deep water (Figure 43). The highest mercury levels (up to 20 µg/g at 5 to 6 cm) were found in core samples taken just south of the FMC plant loading dock in 1972 (Table 41 and 42). High mercury levels in sub-surface sediments off Watts Point are thought to have been introduced in about 1940, from an unknown source.

Core samples taken from tidal flats in front of the FMC chlor-alkali plant showed decreasing levels of mercury and decreasing depths penetrated by the mercury with distance west of the plant (Thompson et al., 1980). Core samples taken in an east-west line along the Squamish River delta west of the FMC plant showed an increase in mercury concentration with proximity to the plant (2 µg/g adjacent to the plant) (Thompson et al., 1980). Beak Consultants (1978) and Macdonald and Wong (1977) reported that highest mercury concentrations were found in the upper estuary close to the FMC chlor-alkali plant and that there was a gradual increase in mercury level with distance moved towards the plant along an east-west line (Tables 44 to 48). Sediment samples collected by the Waste Management Branch and reported in Table 49B indicated mercury levels as high as 18 µg/g adjacent to the abandoned settling pond.

Core samples taken across the width of Mamquam Channel showed relatively low mercury levels (0.03-0.1 µg/g) in the coarse sediments mid-channel (Table 42, 100-HW-W). High surficial levels were recorded above low water levels, perhaps due to atmospheric fallout of mercury (Thompson et al., 1980).

Background mercury levels measured in sediment samples collected away from the influence of the chlor-alkali plant ranged from 0.09-0.11 µg/g in 1977/78 (Thompson et al., 1980).

Comparing 1972-73 survey results, with those of their 1976 survey, Thompson et al., (1980) indicated that mercury levels in the contaminated area were comparable. Levels of mercury near the chlor-alkali plant dock appeared to decrease from 1972-73 to 1976.

The content of methylmercury in surface marine sediments collected in

1976 was found to be less than one percent of the total amount of mercury present (Thompson et al., 1980).

Members of the Air and Water Quality Work Group conducted surveys in June 1980 to investigate the extent of mercury contamination in Cattermole Creek, Mamquam Blind Channel and the area adjacent to Squamish Terminals and the FMC chlor-alkali plant (Figures 35 and 36). The results of these surveys are presented in Tables 40 and 49.

The grab and core samples from Mamquam Blind Channel showed relatively low mercury levels, which were similar to previously recorded levels. In Cattermole Creek, there was evidence of mercury seepage from the FMC effluent pond. Levels of mercury in cores of creek sediments were reported up to 3.4 µg/g in the top 10 cm. Seepage samples collected by the Waste Management Branch, and reported in Table 49B, indicated mercury levels as high as 220 µg/L.

Sediments collected in the area between FMC chlor-alkali plant and Squamish Terminals had the highest concentrations of mercury in the sediments. Levels as high as 33.2 µg/g were recorded in cores taken at 20 to 30 cm depths adjacent to the chlor-alkali loading dock. Contamination of composite sediment samples (from 1.89 - 22.5 µg/g) extended to the area adjacent the Squamish Terminals berthing area.

Data for mercury in sediments dredged and dumped in Howe Sound under Ocean Dumping Control Act permits are included in Table 50. The regulated limit for ocean disposal of wastes containing mercury and mercury compounds as stated in the Ocean Dumping Control Act is 0.75 mg/kg in the solid phase of a waste, and 1.5 mg/kg in the liquid phase of a waste. Proposals for the ocean disposal of dredged sediments are referred through the Environmental Protection Service for consideration by the Regional Ocean Dumping Advisory Committee.

(c) Dredging and Disposal of Mercury Contaminated Sediments

As part of a working group established to review levels of contaminants regulated under the Ocean Dumping Control Act, a review of literature related to the ocean dumping of mercury-containing sediments, and the potential problem of

resuspension of mercury during dredging operations was undertaken (Swiss et al., 1980, Appendix V). The review cited one study which reported that sediment resuspension at the site of a dredging operation caused a short-term release of dissolved mercury to the water column. This was followed by a decrease in dissolved mercury levels, until pre-dredging levels were re-established. This took from 0.5 to 4.5 hours, depending on the sediment type. A similar study reported a decrease in mercury levels in the water following suspension on one occasion, and no change on three other occasions, at dredge and disposal sites. A third study reported slightly elevated surface water mercury levels over a disposal area. Based on results of these three studies, it was concluded that there would seem to be little cause for concern about the possible accelerated accumulation of methylmercury from water by biota at dredge and dump sites.

In the Squamish estuary, a laboratory study undertaken by Seakem Oceanography in association with the Regional Ocean Dumping Advisory Committee, found that mercury-containing sediments which had been collected adjacent to the FMC chlor-alkali plant, released up to 30% of their bound mercury when resuspended in seawater. Most of the mercury recombined with the sediment after 24 hours. Factors likely to affect chemical mobilization of mercury as a result of dredging activities, were listed as pH, salinity, ionic strength, organic content of the surrounding seawater and dredged sediment characteristics. The report cited the redistribution of contaminated sediment over a larger area as a possible consequence of dredging activity (Seakem Oceanography, 1977).

Thompson et al., (1980) point out that while mean mercury levels in biota in the Squamish estuary have decreased substantially since 1970, levels of mercury in sediments do not appear to have been reduced to the same extent. For this reason, Thompson et al. suggest that transfer of mercury from sediments to the biota may not be as important, as was once thought. Methylation within organisms or, less likely, within the water column, may be of more significance in bringing about elevated organic mercury concentrations in biota.

In view of the significant uncertainties concerning the mode of transfer of mercury to the food chain, and the inherent risks of resuspension of mercury from contaminated sediments over an enlarged area as a result of dredging activities, decisions related to dredging, dumping, or re-exposing mercury contaminated sediments (by dredging uncontaminated sediment deposited by the

Squamish River) must be given careful site-specific consideration. In addition, approved dredging and dumping operations should be appropriately monitored.

10.1.4 Other Trace Metals

Before the Britannia copper/zinc mine ceased operations in 1974, a sediment survey was undertaken by Thompson and McComas (1974) in its vicinity. Sediment concentrations of 83 to 1 394 µg/g (mean 562 µg/g) copper and 97 to 1 324 µg/g (mean 357 µg/g) zinc were found. Ten samples analyzed for iron had concentrations ranging from 3.9 to 16.9 µg/g. Copper and zinc concentrations showed a gradual decrease with increasing distance from the mine. Zinc appeared to be more uniformly distributed in the sediments of Howe Sound, although both copper and zinc were considerably elevated as far as 2 kilometres from the mine site (Thompson and McComas, 1974; Thompson and Paton, 1976). Copper and zinc levels in the sediment are shown in Figures 44 and 45, respectively. Both copper and zinc concentrations in sediments decrease with proximity to the head of Howe Sound.

Data for cadmium in sediments dredged in the Squamish area and dumped under Ocean Dumping Control Act permits are outlined in Table 51. The regulated limit for cadmium and cadmium compounds as stated in the Ocean Dumping Control Act is 0.6 mg/kg in the solid phase of a waste, and 3 mg/kg in the liquid phase of a waste.

10.1.5 Polychlorinated Biphenyls (PCB's)

Limited data are available for PCB's in sediments in Squamish. Some data are presented for roadways in the City of Squamish, and a logging road in the Cheekeye area (Table 52). Other data are presented from Ocean Dumping monitoring reports of PCB's in dredge spoils from the Stawamus River and the Mamquam Blind Channel (Table 53). The Ocean Dumping Control Act specifies that organohalogens, a category of compounds to which PCB's belong, may be ocean dumped in concentrations not exceeding one percent of the toxic concentration of that compound to marine, animal or plant sensitive organisms in a bioassay. Historically, it has been recommended that sediments heavily contaminated with PCB's be landfilled.

10.1.6 Pentachlorophenols and Related Compounds

Limited information is available related to chlorophenol accumulations in Upper Howe Sound sediments. Data presented in Table 54 indicate that penta-, tetra- and trichlorophenol were detected in sediments adjacent to Weldwood of Canada Limited. The ratio of the concentration in the sediment to that in the water at this site for penta- and tetrachlorophenols were 22 and 19, respectively.

The Environmental Protection Service identified chlor-alkali and sodium chlorate manufacturing plants as potential sources of hexachlorobenzene (HCB) contamination to nearby aquatic receiving environments. Hexachlorobenzene can be produced through the attack of chlorine on graphite anodes used in electrolytic processes or on hydrocarbon oils used as anode coatings. FMC and Hooker Chemicals were surveyed for hexachlorobenzene contamination in 1977-78.

At FMC composite effluent samples taken from the sewer discharge to the effluent pond contained low HCB concentrations (mean loading of approxmately 0.45 kg/year to the pond). Sediments within the pond contained elevated levels of HCB (19.0 ppm) near the pond entrance. These declined to 5.6 ppm near the pond outlet, and to 0.27 ppm and 0.87 ppm near the final discharge area (Table 55, Figure 37). Hexachlorobenzene was not detected in marine sediment adjacent to the plant nor in mussels or crustaceans collected approximately 200 metres from the final outfall (Department of Environment, EPS, Unpublished). Existing contamination has likely resulted from pre-1975 discharges, since FMC replaced all graphite anodes with dimensionally stable anodes (DSA) or a titanium alloy in 1975.

Sludge samples taken from the Hooker Chemical operation contained no evidence of HCB contamination (Department of Environment, EPS unpublished). Hooker Chemicals has always used only DSA anodes, for which HCB contamination is not a concern.

The Air and Water Quality Work Group collected sediment samples from thirteen locations (indicated in Figure 38) and analyzed the samples for pentachlorophenol and tetrachlorophenol. The results are included in Table 56. Stations 4 and 5 were chosen as stations which were representative of background concentrations.

The data indicate that sediments from Station 2, adjacent to Squamish Terminals, contained approximately four times the levels of both penta- and tetrachlorophenol as were found in Station 4. A dip tank for wood preservation is located near Station 2, and it is believed large quantities of yard drainage enter the estuary near Station 2.

The highest levels of both penta- and tetrachlorophenol were located at Station 11, adjacent to the dip tank for wood preservation at the Weldwood Empire Lumber operation. Station 12, located north of the dip tank, contained approximately one-seventh the level of tetrachlorophenol and one-quarter the level of pentachlorophenol, found at Station 11. However, the levels at Station 12 were at least six times those found for penta- or tetrachlorophenol in any other sediments in Mamquam Blind Channel (except Station 11). Yard drainage enters Mamquam Blind Channel from the Weldwood Empire Lumber operation near Stations 11 and 12.

10.1.7 Ocean Dumping Criteria

The Ocean Dumping Control Act became law in Canada in December 1975, and placed controls on the disposal of wastes at sea. Environment Canada was designated to adminster the Act and to establish a permit system. The permit system regulates disposal of wastes from ships, aircraft, platforms and other man-made structures at sea, as well as the disposal of substances considered to be harmful to the marine environment under special circumstances. The Environmental Protection Service issues permits with various conditions stipulated such as timing restrictions, dump site locations, quantity and type of material to be dumped, method of release and reporting requirements.

In accordance with the Ocean Dumping Control Act, certain substances are prohibited or restricted from ocean disposal. In Schedule I of the Act, certain substances were prohibited when present at concentrations exceeding those specified in Table 57. Schedule II of the Act restricted the deposit of certain other substances (Table 58).

Substances are approved for ocean disposal at designated ocean dump sites. In Upper Howe Sound the ocean dump site is located near Watts Point (49^{o} 38.5' N; 123^{o} 14.0' W). Sediment studies conducted in the vicinity of ap-

proved ocean disposal sites have thus far indicated minimal deleterious effects on the resident biological communities, and no significant elevation in the concentrations of trace contaminants.

10.2 Summary

Sediments in Mamquam Blind Channel were poorly sorted, although sediments adjacent to the mouth of the Stawamus River were better sorted. Finer sized particles occurred in areas of Mamquam Blind Channel influenced by intertidal waters or reduced water velocities. Woodfibre covered the sediments at some locations. All sediments from Cattermole Creek were sorted similarly.

Total organic carbon levels were higher in Mamquam Blind Channel than in the marsh on FMC property, or in Cattermole Creek. The highest total organic carbon levels in Mamquam Blind Channel were recorded in the sediments adjacent to the log booming and chip loading facility. The highest levels in Cattermole Creek were found in the naturally occurring marine sediments along the west bank of the creek.

Studies undertaken related to the dredging of sediments contaminated by mercury have indicated that most mercury released to the water during dredging operations quickly recombined with the sediment. Laboratory tests using Squamish estuary sediments indicated that this period was approximately 24 hours.

In view of the significant uncertainties concerning the mode of transfer of mercury to the food chain, and the inherent risks of resuspension of mercury from contaminated sediments over an enlarged area as a result of dredging activities, decisions related to dredging, dumping, or re-exposing mercury contaminated sediments (by dredging of overlying uncontaminated sediment deposited by the Squamish River) must be given careful site-specific consideration. In addition, approved dredging and dumping operations should be appropriately monitored.

Mercury levels in sediments in the estuary have been reported to be elevated in a 1 550 hectare area adjacent to the FMC chlor-alkali plant. It has been estimated that mercury deposits of an estimated 450 kilograms exist in the

sediments of the area. The highest concentrations of mercury have been reported adjacent to the FMC loading dock. Mercury levels in sediments were comparable between 1972 and 1976, possibly indicating adequate control facilities in place at FMC. This may indicate that the transfer of mercury from sediments to biota may not be as significant as once thought.

Mercury levels in sediments of Mamquam Blind Channel were low, while elevated sediment concentrations of mercury were found in Cattermole Creek.

Copper and zinc in sediments have been found at elevated concentrations as far as two kilometres from the former Britannia mine site (now closed).

Levels of both penta- and tetrachlorophenol were found to be highest in sediments adjacent to wood preservation dip tanks located at Squamish Terminals and the Weldwood Empire Lumber operation. It is believed these high levels in the sediments have resulted from uncontrolled yard drainage entering waterways after passing through areas used for wood preservation.

XI Toxicant Accumulation in Biota

11. TOXICANT ACCUMULATION IN BIOTA

11.1 Presentation and Discussion of Data

11.1.1 Mercury

Indications of mercury contamination of biota in Upper Howe Sound in 1970 precipitated a closure of commercial and sports fisheries by the Department of Fisheries. The ban on the taking of salmon, trout and herring, was removed shortly thereafter while the closure was maintained until 1978 for other fish, shellfish and crustaceans (see Figure 26 delineating area of closure). Currently all recreational fisheries have been reopened while the commercial fishery remains closed for management purposes.

Annual surveys to determine the mercury content in marine and estuarine organisms in Howe Sound have been carried out by Department of Fisheries and Oceans and Beak Consultants on behalf of FMC from 1970 to 1978. Values determined by these and a number of smaller scale studies undertaken by the provincial government, are presented in Tables 59 to 61. It should be noted that the standard for mercury content in marine and freshwater animal products recommended by the Canadian Department of National Health and Welfare as safe for human consumption is 0.5 µg/g (ppm) on a wet weight basis.

a) Fish

The spiny dogfish (Squalus acanthias) was the only fish species sampled which consistently had a mean annual mercury level greater than the recommended health standard (values as high as 2.92 ppm wet-weight). Samples taken from coastal waters elsewhere in southern British Columbia indicate that dogfish commonly show elevated mercury levels. Rockfish (Sebastes spp.), lingcod (Ophiodon elongatus) and flounders (Family Peuronectidae) showed elevated mean annual levels in some early sampling years (1970-72) but 1977-78 mean levels were below 0.5 µg/g. Nevertheless, as recently as 1977/78 individual specimens from each of these groups were found to have high mercury levels (see Table 60).

Non-resident species and those with shorter life spans (e.g., sal-

monids, Onchorhynchus spp. and herring, Clupea harengus pallasi) were generally found to have low mercury levels (less than 0.2 µg/g).

Evidence of mercury accumulation with age (as determined by body length) was demonstrated for copper and quillback rockfishes (Sebastes caurinus and S. maliger respectively) for 1970 to 1975 data, (Harbo and Birtwell, 1978a).

b) Invertebrates

Dungeness crabs (Cancer magister) taken from Upper Howe Sound in 1970 had extremely high levels of mercury (1970 mean 3.61 ± 4.17 µg/g; range 0.22-13.4 µg/g; n=29, Department of Fisheries). A steady decrease was noted in mean annual levels (see Tables 59, 60) to the 1977/78 mean level of 0.16 ± 0.11 µg/g (range 0.02-0.42 µg/g, n=71). This decrease could be associated with recruitment and mortality, as well as with reduction in mercury losses from the chlor-alkali plant. Results indicate the mercury content of C. magister to be approaching background or "natural" levels (Harbo and Birtwell, 1978a). These findings are consistent with those of Beak Consultants who undertook a crab sampling program on behalf of FMC during the period 1971-78.

A few shrimp (n=4) sampled in Upper Howe Sound in 1970 had high mercury levels (mean 0.92 ± 1.22 µg/g, range 0.31-2.75). Prawns, Pandalus playtceros, sampled in 1977 and 1978, had low mercury levels, ranging from 0.02 to 0.81 µg/g (mean = 0.17 ± 0.10, n=94) on a wet weight basis (Harbo and Birtwell, 1978b).

Molluscs, collected infrequently, generally showed low mercury levels. Mussels (Mytilus edulis), taken adjacent to the chlor-alkali plant from 1972 to 1975, showed a mean mercury level of 0.42 µg/g. Individuals sampled by the B.C. Ministry of Environment in 1979 just west of the plant's barge slip, contained 0.96 µg/g mercury (Ministry of the Environment, unpublished data, Table 61). The few clams and oysters sampled by Department of Fisheries from 1970 to 1975 showed no elevation in mercury levels. Clams taken in 1979 by the B.C. Ministry of Environment, from the beach adjacent to the chlor-alkali plant, contained 2.56 µg/g mercury (Ministry of the Environment, unpublished data). These dif-

ferent values could possibly be explained by differences in the years samples were obtained, the locations of sampling sites, or analytical methodologies.

c) Algae

Results of analyses of the intertidal seaweed Fucus gardneri from the vicinity of the chlor-alkali plant and Upper Howe Sound are presented in Table 62. All samples were at or below 0.05 µg/g.

d) Humans

Tests were conducted by Health and Welfare Canada in 1978 for mercury in blood samples taken from 17 residents of the Squamish reserve. Values obtained were within a range from 0 to 19 µg/L, and were considered within the normal accepted limits (Department of National Health and Welfare, 1978).

11.1.2 Other Trace Metals

In addition to mercury, metals considered hazardous to humans as well as marine organisms include cadmium, lead, zinc and copper (Bernhard and Zahtera, 1975).

Maximum permissible levels of these metals in aquatic animal products (wet weight) are 10 µg/g for lead and 100 µg/g for zinc and copper. An acceptable level for cadmium has not yet been determined (Government of Canada, 1975). An approximate conversion factor for wet-weight levels to dry-weight is to multiply the wet-weight levels by a factor of 5. Most data in scientific literature are presented on a dry-weight basis.

Trace metal data collected between 1977 and 1979 for Howe Sound crustaceans and fishes (Department of Fisheries and Oceans, unpublished), molluscs and an isopod species (B.C. Ministry of Environment, unpublished) are presented in Tables 60 to 62. Zones referred to in Table 60 are depicted in Figure 26. Although the analysis of the data has not been completed, preliminary examination indicates that there appears to be no evidence of cadmium, lead, zinc, or copper accumulation above levels accepted as safe for human consumption. Further analysis of this data will include comparison with trace metal levels found in similar organisms in other south coast locations to determine if levels found in Howe Sound organisms are elevated.

Results of analyses of copper and zinc in Fucus gardneri from the vicinity of the chlor-alkali plant are presented in Table 62. Copper values ranged from 16.3 to 149 µg/g. Zinc values ranged from 90.3 to 164 µg/g.

11.1.3 Pentachlorophenol and Related Compounds

There is limited information available concerning the accumulation of chlorophenols in the biota of the Squamish estuary (see Table 63). In 1978, ten Dungeness crabs (C. magister) and four staghorn sculpins (Leptocottus armatus) were sampled adjacent to Weldwood Empire Lumber, in Mamquam Blind Channel. A small amount of tetrachlorophenol was noted in crab muscle tissue (0.08 times that found in adjacent sediment). Somewhat greater amounts of penta- and tetrachlorophenol (respectively 0.66 to 0.64 times that in the adjacent sediment), and hexachlorobenzene were noted in sculpin liver tissue (Department of the Environment, Environmental Protection Service, 1979). It is likely that the accumulated tetrachlorophenol and hexachlorobenzene were contaminants of the original pentachlorophenol formulation. Lethal and sub-lethal concentrations of the various compounds have yet to be determined.

11.2 Fish Kills

Information related to fish kills which have occurred in the period from 1971 to 1978 is included in Table 64.

It is estimated that 3 000 juvenile herring were killed in Mamquam Blind Channel in June 1975. This was the largest reported fish kill on record. The cause of the kill was not determined.

Products associated with wood preservation facilities (penta- and tetrachlorophenol) were deemed responsible for a fish kill in October 1973 in Mamquam Blind Channel where 1 000 adult and juvenile coho and shiner were killed. Similarly, penta- and tetrachlorophenol were implicated as the cause of a fish kill in October 1977, in Mamquam Blind Channel.

11.3 Summary

Recreational fisheries in Upper Howe Sound are currently open, following a 1970 closure due to possible mercury contamination. The commercial fishery is presently closed for management purposes.

The spiny dogfish (Squalus acanthias) was the only fish species sampled which consistently had mercury levels which exceed the recommended health standard. However, this appears to be typical of dogfish in coastal waters in southern British Columbia. Some individual specimens of rockfish (Sebastes spp.), lingcod (Ophiodon elongatus), and flounders (Family Pleuronectidae) have been found to have high mercury levels, although 1977-78 mean values for each of these groups were within limits specified as safe for human consumption.

The mercury levels in dungeness crabs (Cancer magister) have decreased from extremely high values in 1970 to values approaching "natural" levels. Most other invertebrates had low mercury levels. Mercury levels in algae and humans, were low.

There is no evidence of cadmium, lead, zinc, arsenic, or copper accumulation in Howe Sound fishes.

Pentachlorophenol and tetrachlorophenol have been implicated as the causes of two fish kills which occurred during 1973 and 1977.

XII Conclusions and Recommendations

12. CONCLUSIONS AND RECOMMENDATIONS

12.1 Conclusions

12.1.1. Hydrology

The dykes constructed along the Squamish River are likely to provide protection from flooding from most peak floods. Flooding which occurred during 1980 did not result from failure of the dyke system, but from water backing up along a creek.

The purpose of the training dyke along the southern portion of the Squamish River was to prevent fanning of the delta to the east. However the delta is advancing at a steady rate, possibly extending towards the port facilities and the proposed harbour. This has been apparent in the upper, middle, and lower estuary sections.

The estuary east of the training dyke has changed from a brackish to a more marine condition due to the almost complete elimination of riverine water flow to the central basin.

The District of Squamish, in the period from 1972 to 1978, used an average of 7 700 m^3/d of water, or a maximum of only 5% of the Stawamus River mean monthly flow. Water shortages are not anticipated at the present growth demands. Industry consumes approximately 5% of the average daily water distributed by the District of Squamish.

12.1.2 Air Emissions, Liquid Effluents, and Solid Wastes

The Weldwood of Canada Empire Lumber operation has not reported monitoring data as required by their pollution control permit. As well, extremely high levels of pentachlorophenol and tetrachlorophenol have been reported in sediments adjacent to the wood preservation facility at this operation, and a fish kill attributed to these phenolic compounds has occurred in Mamquam Blind Channel.

The wind patterns in the Squamish area make air pollution at Woodfibre of importance to Squamish residents. The odour problem noted at Squamish would be less severe if permitted values for bivalent sulphur compounds were met at Woodfibre.

FMC of Canada Ltd. has taken extensive steps to upgrade discharges from its operation. The abandoned settling pond is currently being upgraded by confining mercury contaminated sludge to a restricted area which has been covered with an impermeable membrane. Significant amounts of mercury lost which cannot be accounted for in the process are the subject of discussions between government agencies and FMC. Although high mercury levels have been recorded in sediment samples, it is believed that these have resulted largely from discharges from FMC prior to 1972.

CanadianOxy (Hooker) Chemicals have met limits for air emissions and pH as specified in their pollution control permit for the disposal of brine sludge. Leachate from the brine sludge landfill may enter a ditch draining to Cattermole Creek.

Oil levels in effluent from Squamish Terminals have exceeded the limit specified in its pollution control permit for 46% of the limited data. Evidence of the effluent from the rock seepage pit was noted in the intertidal zone. Analyses of sediments adjacent to the wood preservative dip tanks indicated high levels of pentachlorophenol and tetrachlorophenol.

Both the Central STP and the Mamquam STP experience excessive BOD_5 and suspended solids concentrations due to high flows through the treatment plants. These high flows render the treatment process useless at those times. Samples collected by the District of Squamish for bacteriological analyses have not been collected in bottles containing sodium thiosulphate, negating the accuracy of this bacteriological data.

The effluent discharge point from the Mamquam STP into the Squamish River frequently provides no dilution to the effluent. This undiluted discharge is a potential public health and fisheries hazard. This discharge persisted even after the District of Squamish had taken steps to dredge the river

and provide adequate dilution. The placement of this discharge as a submerged outfall in the Squamish River would provide more adequate dilution, and thus reduce potential ammonia toxicity associated with this effluent. The need for chlorination and dechlorination should be reviewed.

The municipal solid waste disposal site operated by the District of Squamish up until June 1980, was closed due to high groundwater levels in the area. The District of Squamish has adequately covered dump faces. Methane generation at this site will be in proportion to the operating life of the site.

12.1.3 Hazardous Chemicals

Although considerable quantities of bulk chemicals are shipped into and out of the study area, the exact amounts are not known. No contingency plan for spills exists.

12.1.4 Ambient Air

It has been recognized that the local topography of the Howe Sound area makes air pollution potential in the southwest coast region of concern.

12.1.5 Riverine Water Quality

Most water chemistry parameters in the Stawamus, Cheakamus, Mamquam and the Squamish rivers excluding copper, zinc, and manganese met the water quality criteria for the propagation and maintenance of aquatic life. It has not been established whether copper, zinc, and manganese pose a threat to aquatic resources. The median reported values for most parameters were equal to, or lower, than the median values reported for all monitored B.C. streams. Dissolved oxygen concentrations were higher. The influence of freshet is to decrease alkalinity, hardness, and magnesium, and to increase phosphorus and suspended solids. These increases result from the erosion of bank material and the resuspension of sediments. Sampling undertaken by government agencies has typically coincided with freshet, resulting in a paucity of data related to low flow conditions.

Riverine waters are poorly buffered against alkaline discharges. Saline waters at depth in the Squamish River and Cattermole Creek are much better buffered against both alkaline and acidic discharges, than surface waters at the same locations.

Theoretical calculations indicated that ammonia toxicity will not likely be a problem in the Squamish River. Ammonia toxicity will only become a problem should temperature and/or alkalinity be elevated simultaneously. This is unlikely under present conditions.

12.1.6 Estuarine Water Quality

Reduced freshwater input to the east delta has resulted in higher surface salinity values than encountered in the west delta. The Squamish estuary approximates a typical fjord system with the Squamish River forming a freshwater lens over deeper saline waters, and mixing occurring along the full length of Howe Sound. Mamquam Blind Channel is relatively well mixed, with a freshwater lens developing at high tide.

Higher water temperatures have been recorded in the winter in the central basin and in the east delta, than in the Squamish River or the west delta. The higher temperatures can potentially influence the nature of aquatic communities.

There have not been any areas of consistent oxygen depletion reported in the study area. Low dissolved oxygen values were recorded at depths from 200 to 250 metres, north of the sill, in the autumn of 1977 and 1978. This may be a regular occurrence in Howe Sound.

12.1.7 Sediment Quality

Sediments in Cattermole Creek are better sorted than in Mamquam Blind Channel due to the level of man-induced activities adjacent to the channel. Sediments in Mamquam Blind Channel are poorly sorted, although areas such as the mouth of the Stawamus River which are influenced by natural phenomena, are better sorted. Woodfibre in the sediments of Mamquam Blind Channel are influenced by log handling. Many of the samples were darkly coloured, and

odorous. The presence of the woodfibre resulted in higher total organic carbon levels in the Mamquam Blind Channel sediments, than in those from Cattermole Creek.

Mercury levels in Squamish estuary sediments are elevated adjacent to the FMC chlor-alkali plant. In general, most mercury released to the water in dredging operations quickly recombines with the sediment. For the Squamish estuary, the period based upon laboratory tests was estimated to be 24 hours. Dredging does cause mercury contaminated sediments to be spread over a larger area. Mercury levels in sediments were comparable between 1972 and 1976.

12.1.8 Toxicant Accumulation in Biota

The spiny dogfish (Squalus acanthias) is the only fish species which has consistently exceeded the recommended health standard for mercury. High mercury levels are common in dogfish in coastal waters of southern British Columbia. However, individuals of rockfish, lingcod, and flounders have been occasionally found to contain high mercury levels. Mercury levels in dungeness crabs (Cancer magister) have decreased from extremely high values reported in 1970 and are approaching "natural" levels.

12.2 Recommendations

1. Decisions related to dredging, dumping, and/or re-exposing contaminated sediments should be studied on a site specific basis. Approved dredging and dumping applications should be appropriately monitored.

2. Monitoring of sedimentation processes, especially in the area of any proposed harbour, should continue.

3. Any proposed developments which would require large quantities of Stawamus River water, either directly or through the District of Squamish water distribution system, should be fully investigated in order that adequate freshwater supplies be maintained.

4. The Weldwood of Canada Empire Lumber operation should:

   (a) prevent pentachlorophenol and associated substances entering Mamquam

Blind Channel, by diverting yard drainage away from areas where wood preservation takes place or where treated wood is stored, and by removing the dip tank from close proximity to the bank of Mamquam Blind Channel.

(b) investigate methods to reduce the spillage of wood chips during the loading of barges.

5. The Woodfibre operation should take the necessary steps to meet the conditions of its pollution control permit for air emissions in order to reduce the odour problem in Squamish.

6. FMC of Canada Ltd. should:

(a) complete during 1980, the work of filling the abandoned settling pond and covering it with an impervious layer.

(b) continue to monitor groundwater wells adjacent to its abandoned settling pond three times per year, as outlined in its pollution control permit for monitoring groundwater wells adjacent to its solids waste disposal site.

(c) continue efforts to reduce losses of mercury from all sources.

(d) determine the remaining sources of mercury as yet unaccounted for.

7. Squamish Terminals should:

(a) take steps to improve the recovery of waste oil.

(b) make periodic inspections of the intertidal zone influenced by exfiltrate from the rock seepage pit.

(c) take steps to reduce levels of pentachlorophenol and associated substances being transported into the estuary, by diverting yard drainage away from areas where wood preservation takes place, or where treated wood is stored.

8. The District of Squamish should:

   (a) construct flow equalization chambers at the Central STP and the Mamquam STP in order to improve plant performance. The facilities should be constructed only after an extensive engineering study of the requirements at each plant is undertaken.

   (b) extend the Mamquam STP outfall to a location which ensures adequate dilution and dispersion of effluent.

   (c) determine the need for new flow metering devices which will accurately record the flows at each plant.

   (d) re-assess the need for year-round chlorination of the effluents from both sewage treatment plants. Dechlorination facilities should also be considered.

   (e) undertake studies to assess the affect of the effluent on ammonia values in the estuary under worst case conditions.

9. Any proposed developments for the abandoned District of Squamish solid waste disposal site, or immediately adjacent lands, should assess the potential of methane generation from the abandoned site, and its possible effect on the proposed development.

10. Future riverine water quality monitoring programs should recognize the historical data gaps related to low flow conditions, and should attempt to fill these gaps at all monitoring stations.

11. Proposed discharges of alkaline or acidic wastes into riverine waters should be made through submerged outfalls. Areas of the estuary with low salinity or with poor water exchange, should not receive alkaline wastes.

12. Continuous discharges of wastes having high oxygen demand should not be allowed to waters at great depth, north of the sill of Howe Sound.

13. The Waste Management Branch should continue to:

    (a) monitor groundwater conditions adjacent to the Weldwood of Canada Empire Lumber solid waste disposal site.

    (b) monitor leachate from the CanadianOxy (Hooker) Chemicals brine landfill to determine the impact on Cattermole Creek.

    (c) make periodic inspections at Squamish Terminals of the intertidal zone influenced by exfiltrate from the rock seepage pit.

    (d) monitor leachate from the closed District of Squamish solid waste disposal site in order to assess leachate toxicity, and the zone of influence of the leachate.

14. A complete review of the nature and quantity of chemicals shipped into and out of the Squamish area should be undertaken. A contingency plan protecting both the public and the environment should be formulated.

15. A one year study of the haze problem near Squamish should be undertaken to assess its degree and source.

16. A one year study of temperature inversion, winds, and air quality in areas of the Howe Sound area designated for industrial use should be undertaken.

17. Further testing for trace organic contaminants in discharges should be undertaken, with the emphasis of such a program being to determine the source and loading of these substances to the estuary, any bioaccumulation in the environment, and practical steps which might be taken to minimize the discharge of these chemicals.

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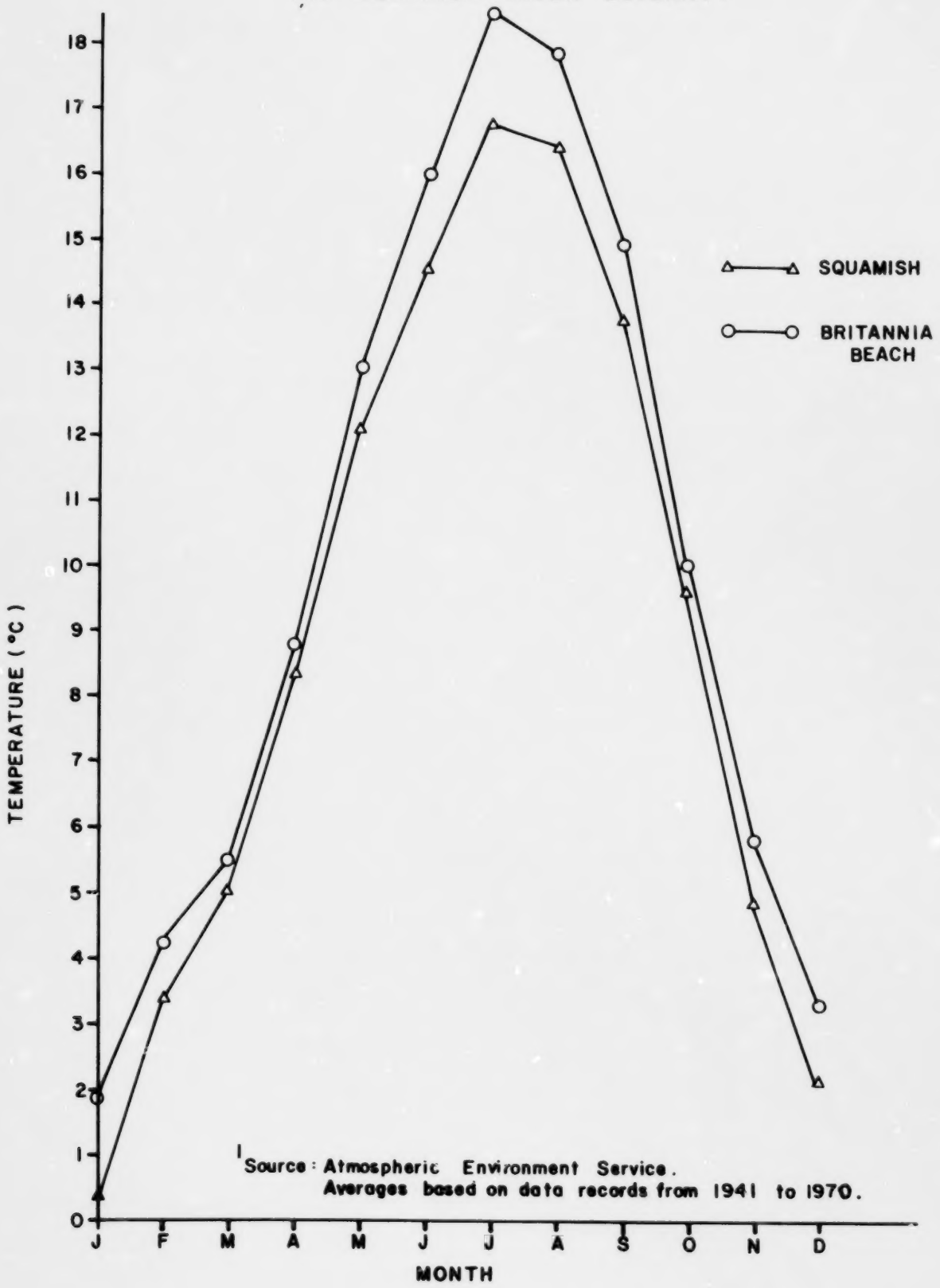
Figures

FIGURE 1.

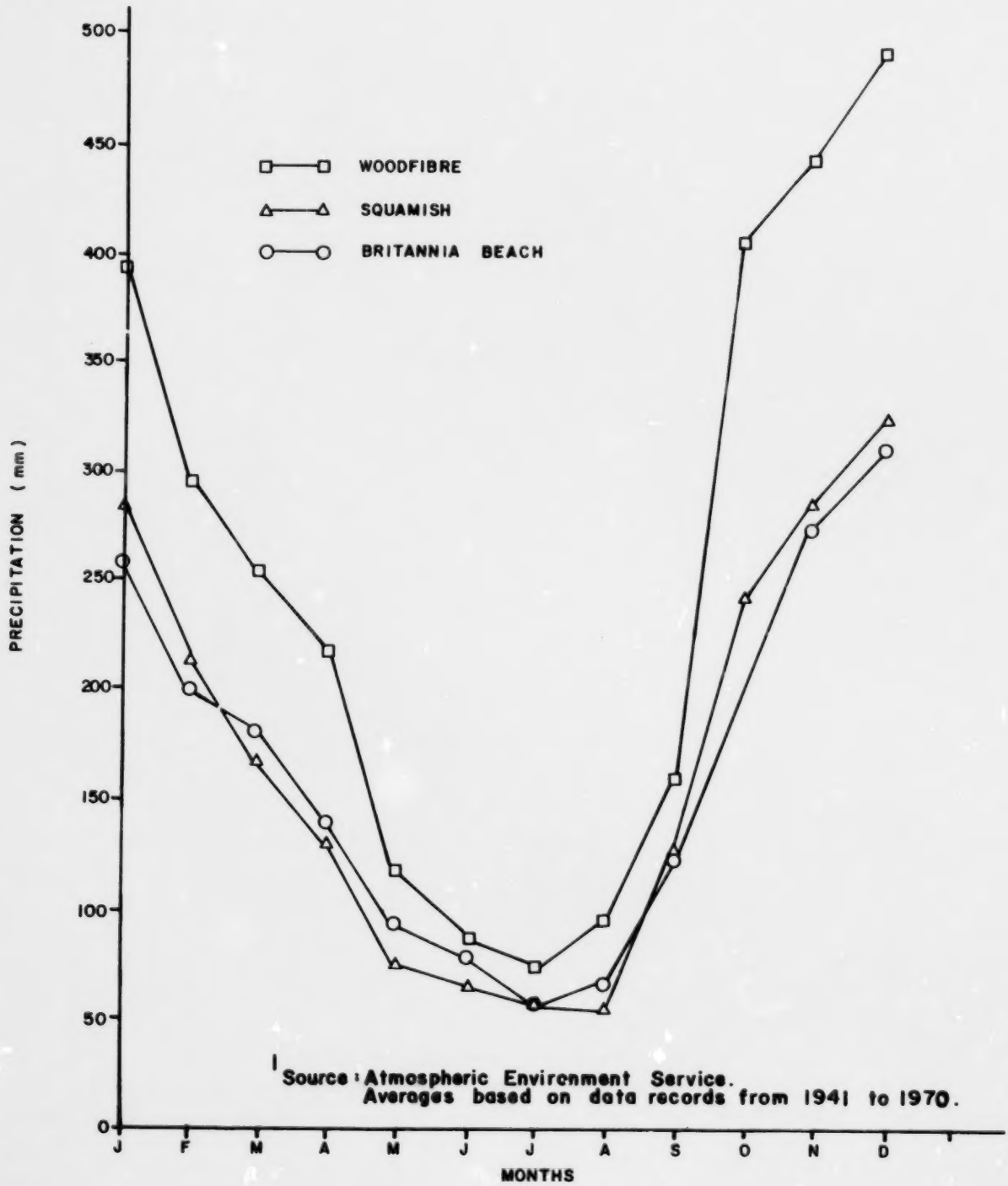
AVERAGE MONTHLY AMBIENT AIR TEMPERATURES[1] FOR THE SQUAMISH RIVER ESTUARY.



[1] Source: Atmospheric Environment Service.
Averages based on data records from 1941 to 1970.

FIGURE 2 .

AVERAGE MONTHLY PRECIPITATION LEVELS[1] FOR THE SQUAMISH RIVER ESTUARY .



[1] Source : Atmospheric Environment Service.
Averages based on data records from 1941 to 1970.

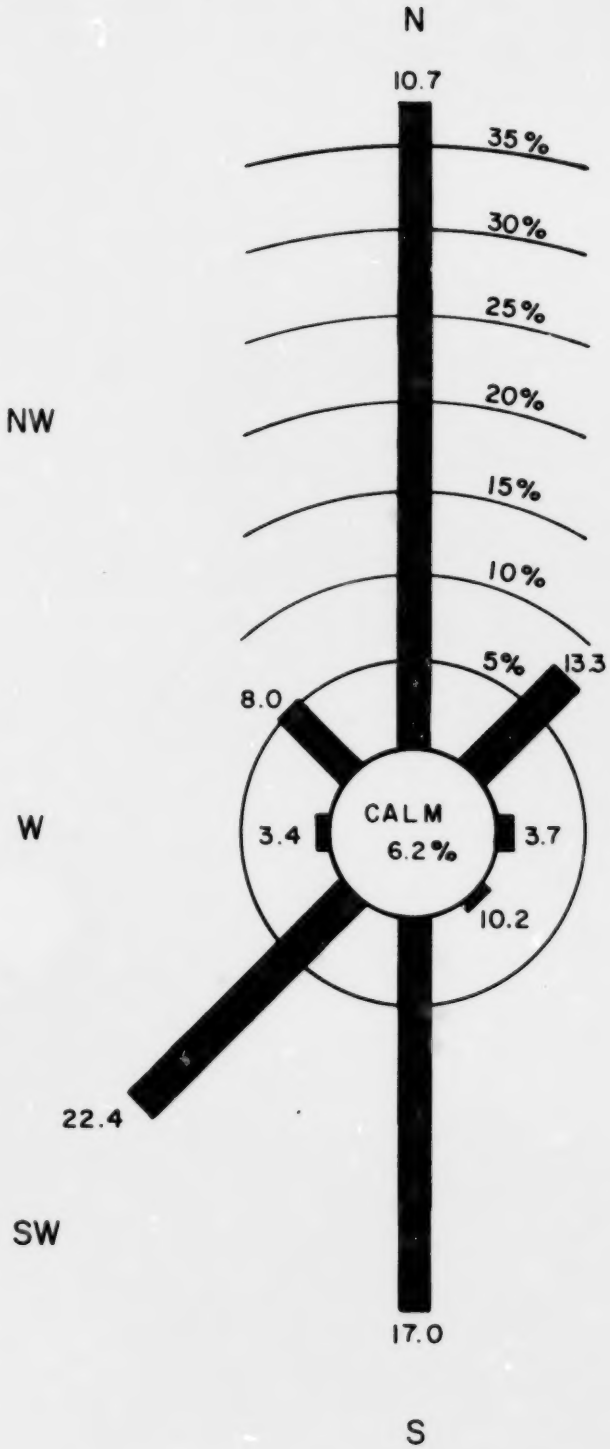


FIGURE 3 .

WIND ROSE ,
SQUAMISH, B.C.
(F.M.C. CHEMICALS ,
JAN. 1972 to MAY 1976,
FROM ATMOSPHERIC
ENVIRONMENT SERVICE)

Percentage frequency of wind by direction (1 inch = 10 percent)

Mean wind speed by direction in km / hr.

FIGURE 4. MEAN MONTHLY FLOWS FOR THE SQUAMISH, CHEAKAMUS MAMQUAM AND STAWAMUS RIVERS (1966 to 1978, inclusive). THE MAXIMUM AND MINIMUM MEAN MONTHLY FLOWS FOR THE SQUAMISH ARE ALSO GIVEN.

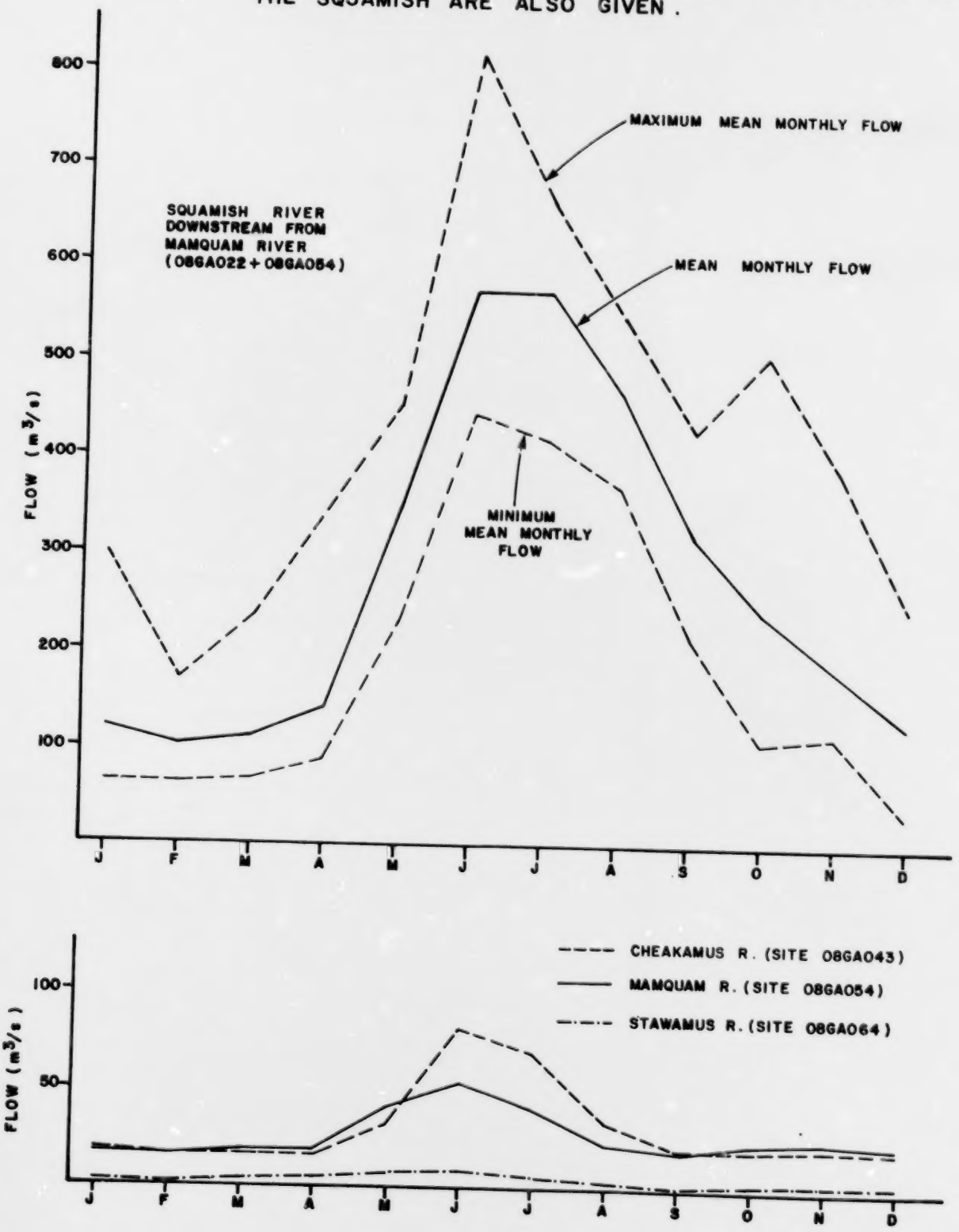
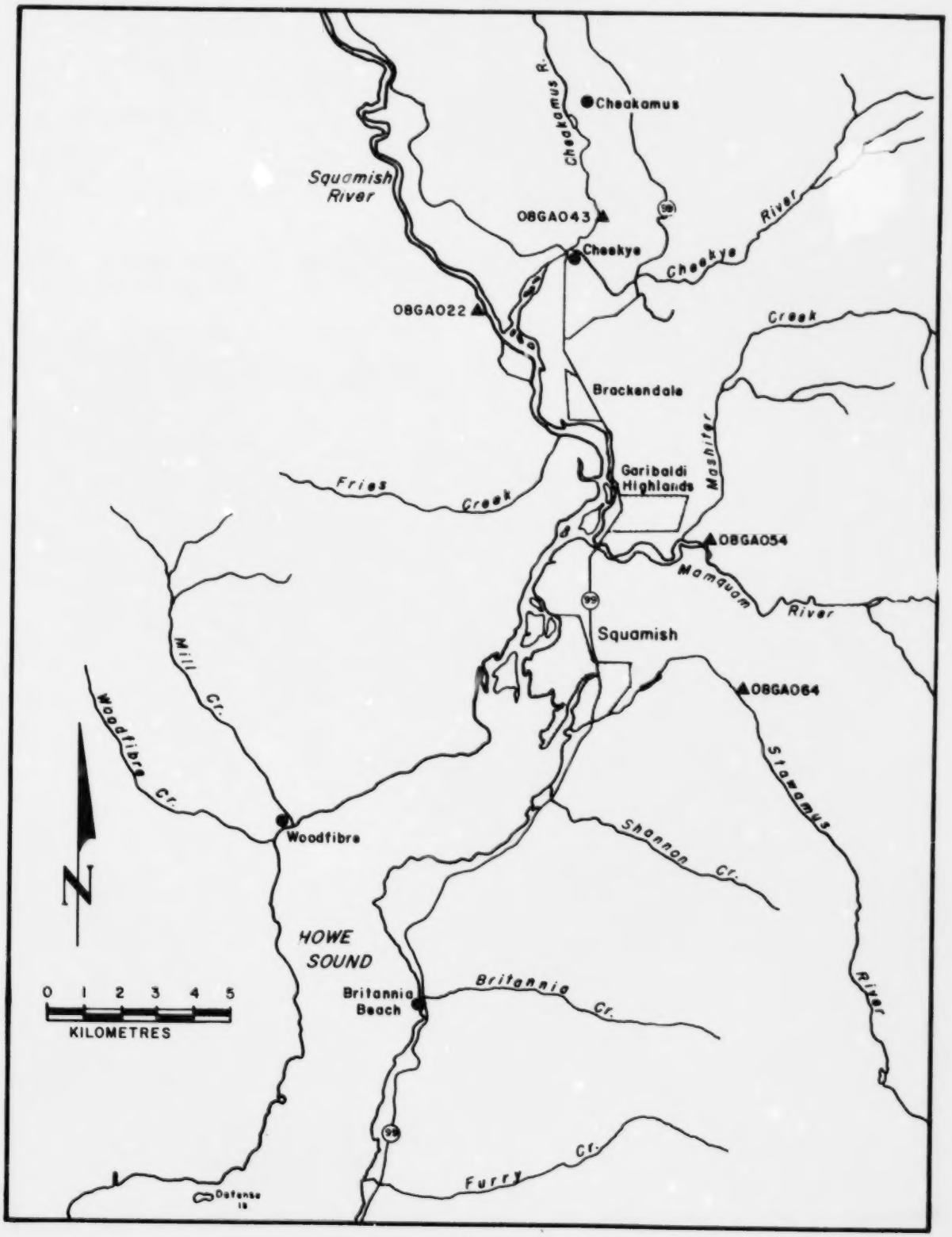


FIGURE 5 . LOCATION OF STREAMFLOW MONITORING SITES IN THE SQUAMISH AREA.



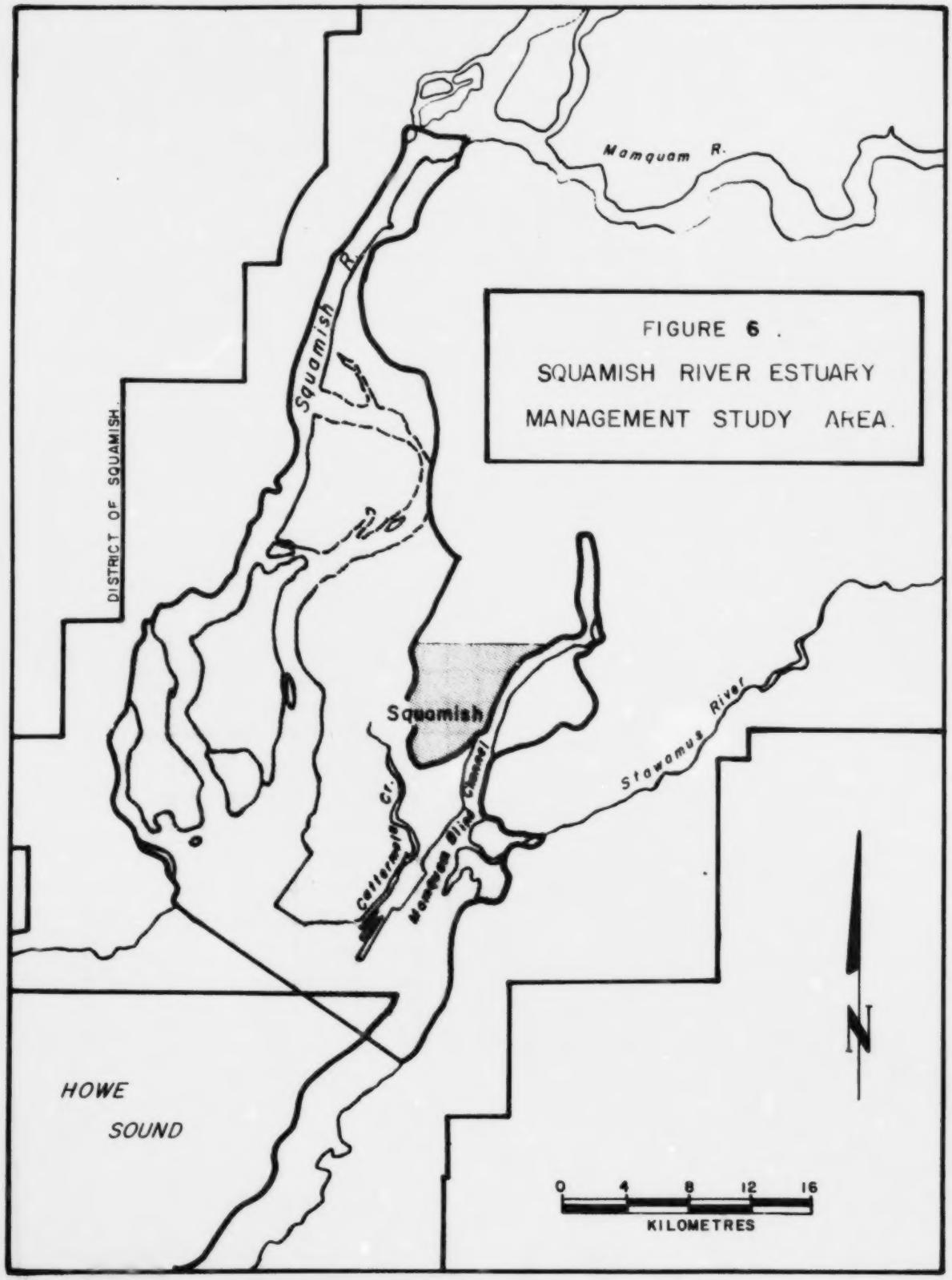
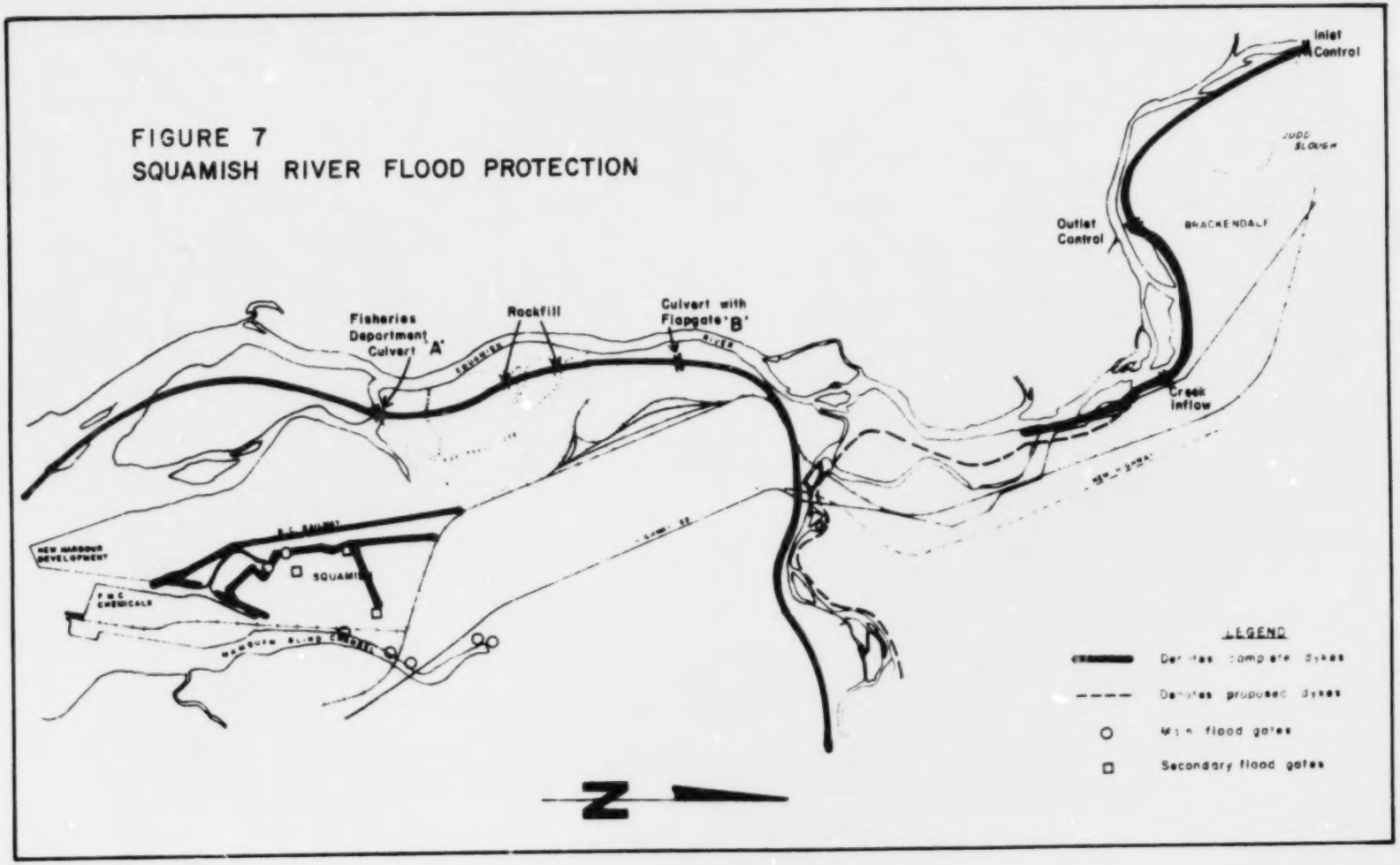


FIGURE 6 .
SQUAMISH RIVER ESTUARY
MANAGEMENT STUDY AREA.

FIGURE 7
SQUAMISH RIVER FLOOD PROTECTION



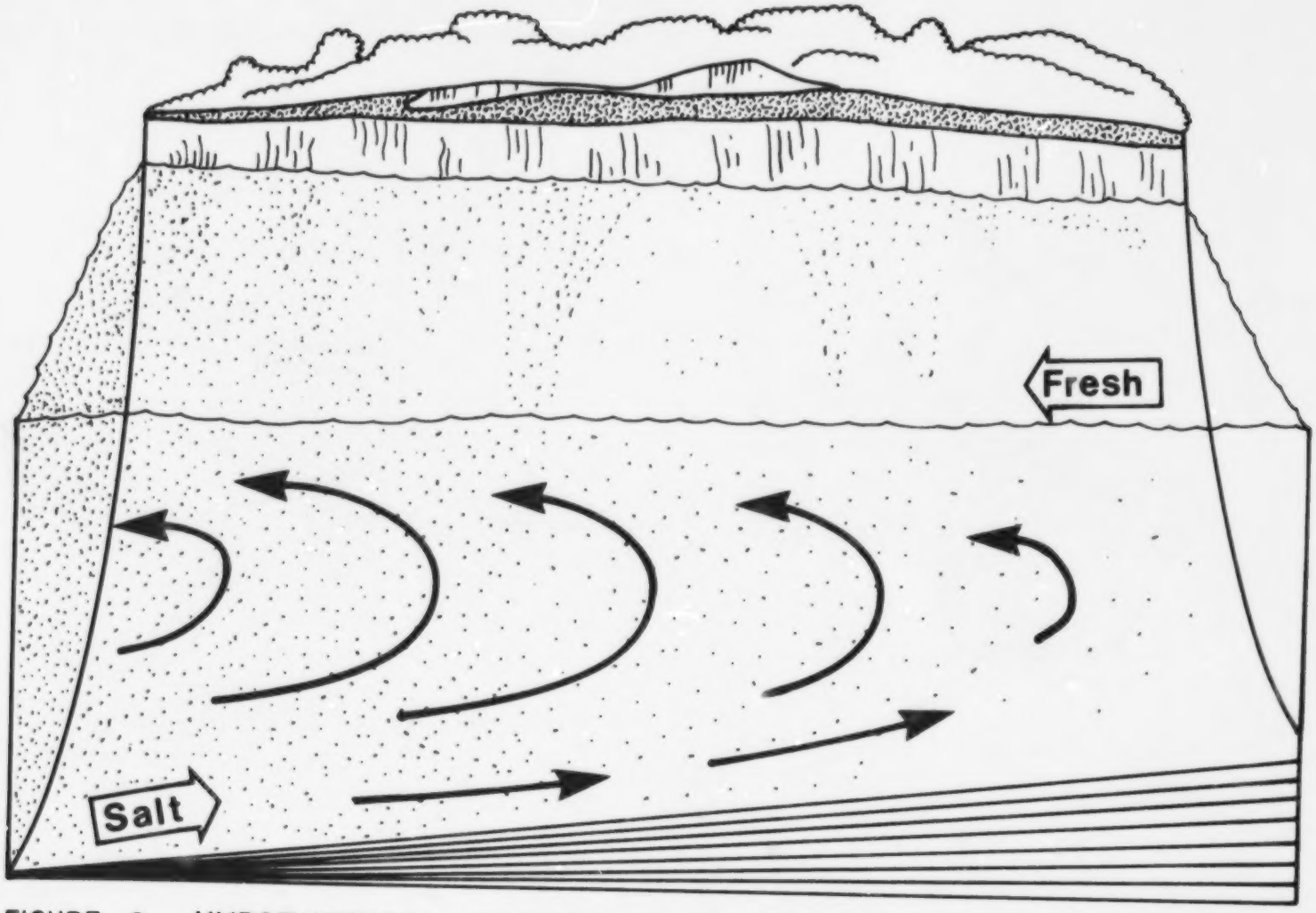


FIGURE 8 . HYPOTHETICAL ESTUARY WITH NEGLIGIBLE TIDES AND LITTLE VERTICAL MIXING (FROM PERKINS , 1974)

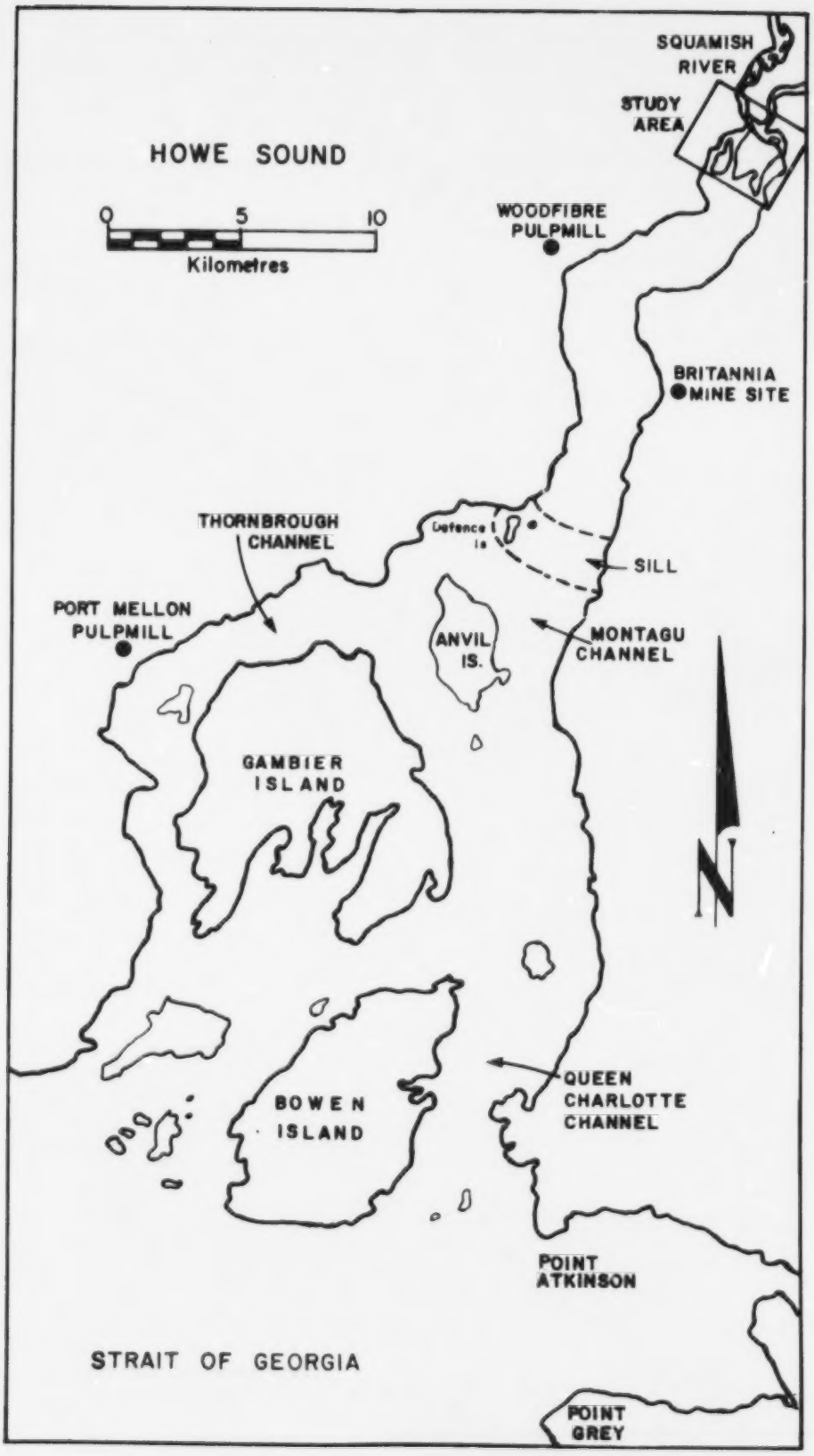


FIGURE 9 . MAP OF HOWE SOUND AND SQUAMISH ESTUARY .

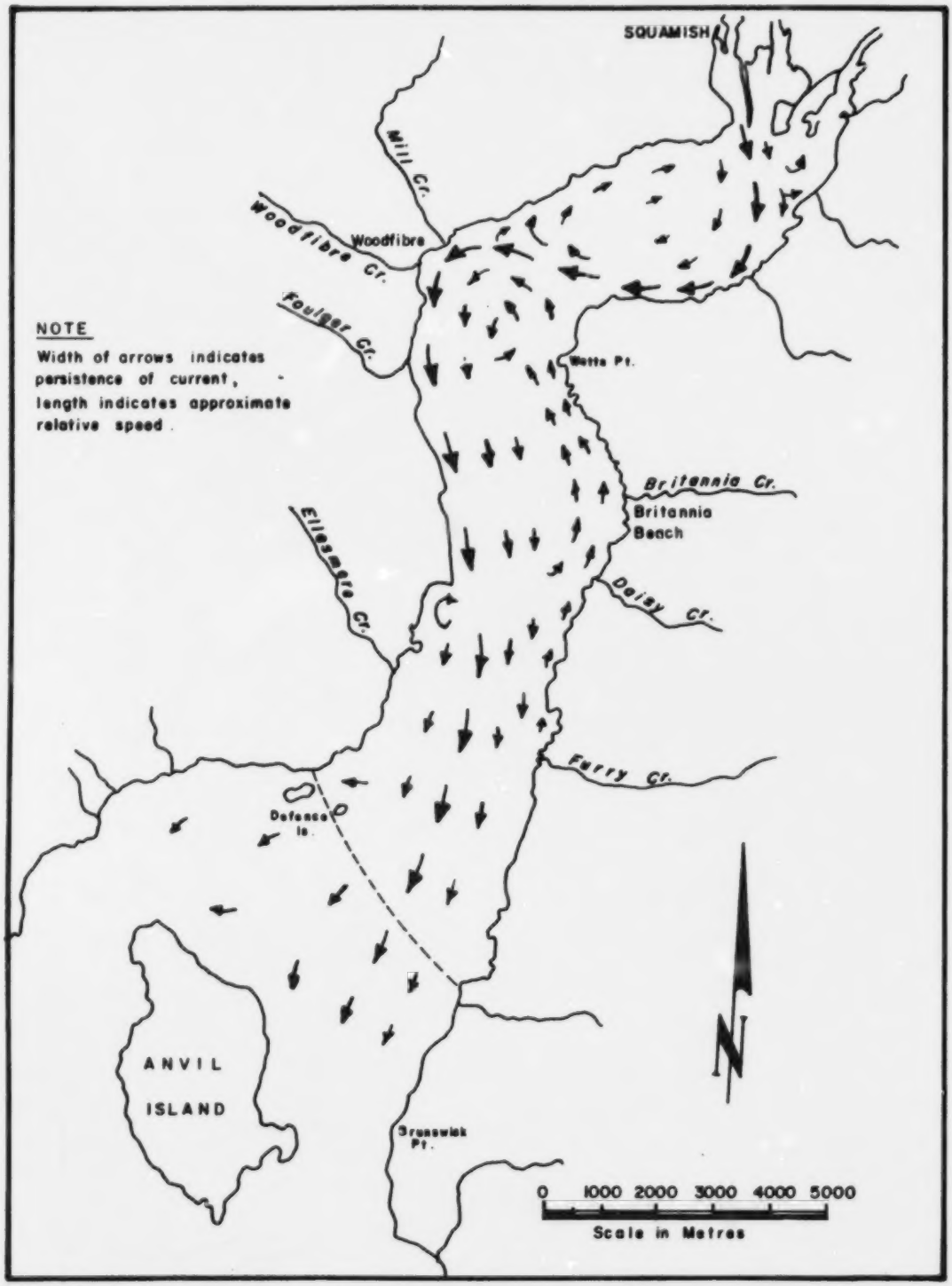


FIGURE 10. GENERAL SURFACE CIRCULATION IN HOWE SOUND WITH WIND EFFECTS AVERAGED OUT (From Buckley and Pond, 1976)

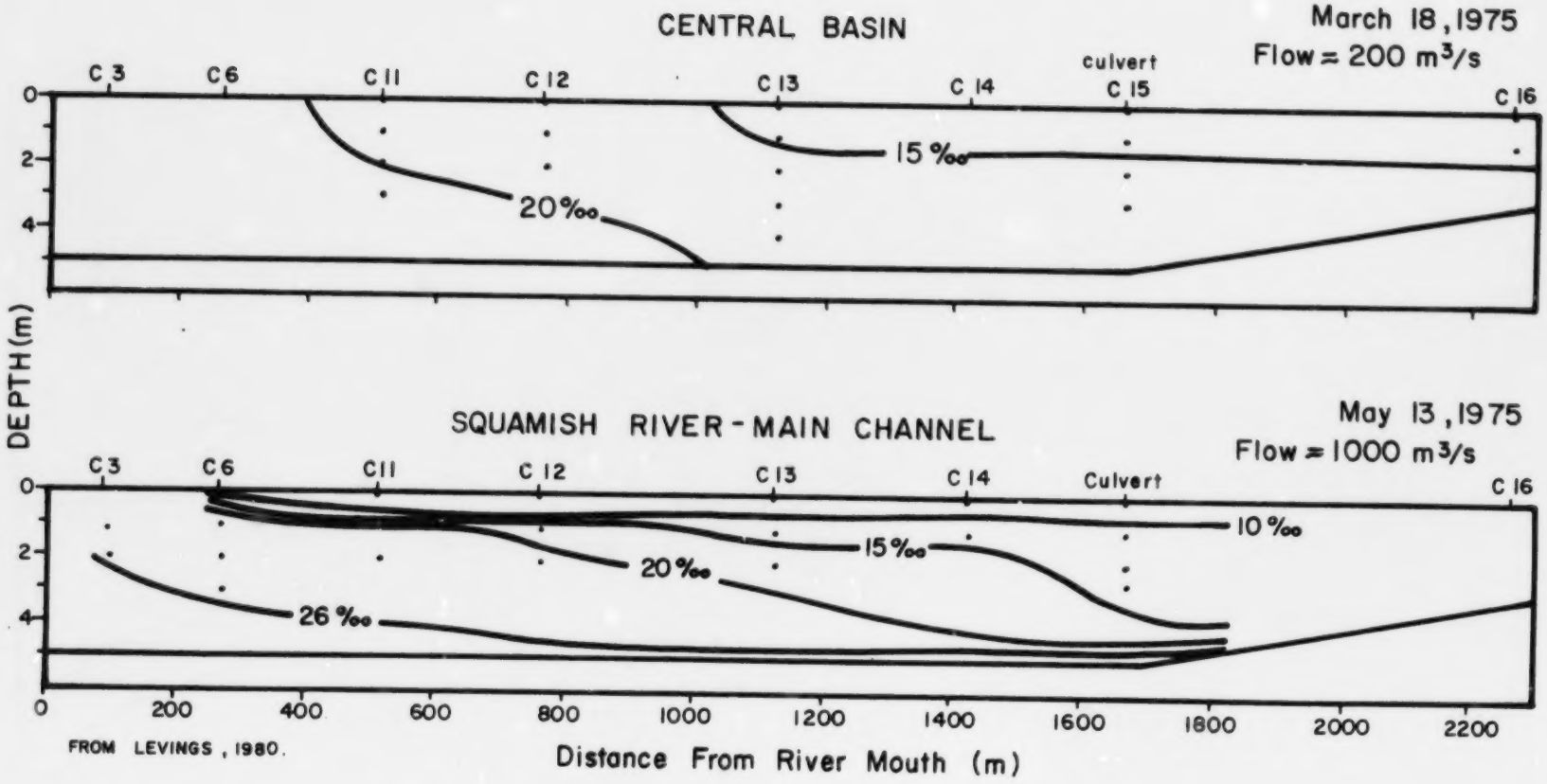


FIGURE 11 . VERTICAL SALINITY PROFILES IN CENTRAL BASIN AND SQUAMISH RIVER MAIN CHANNEL.

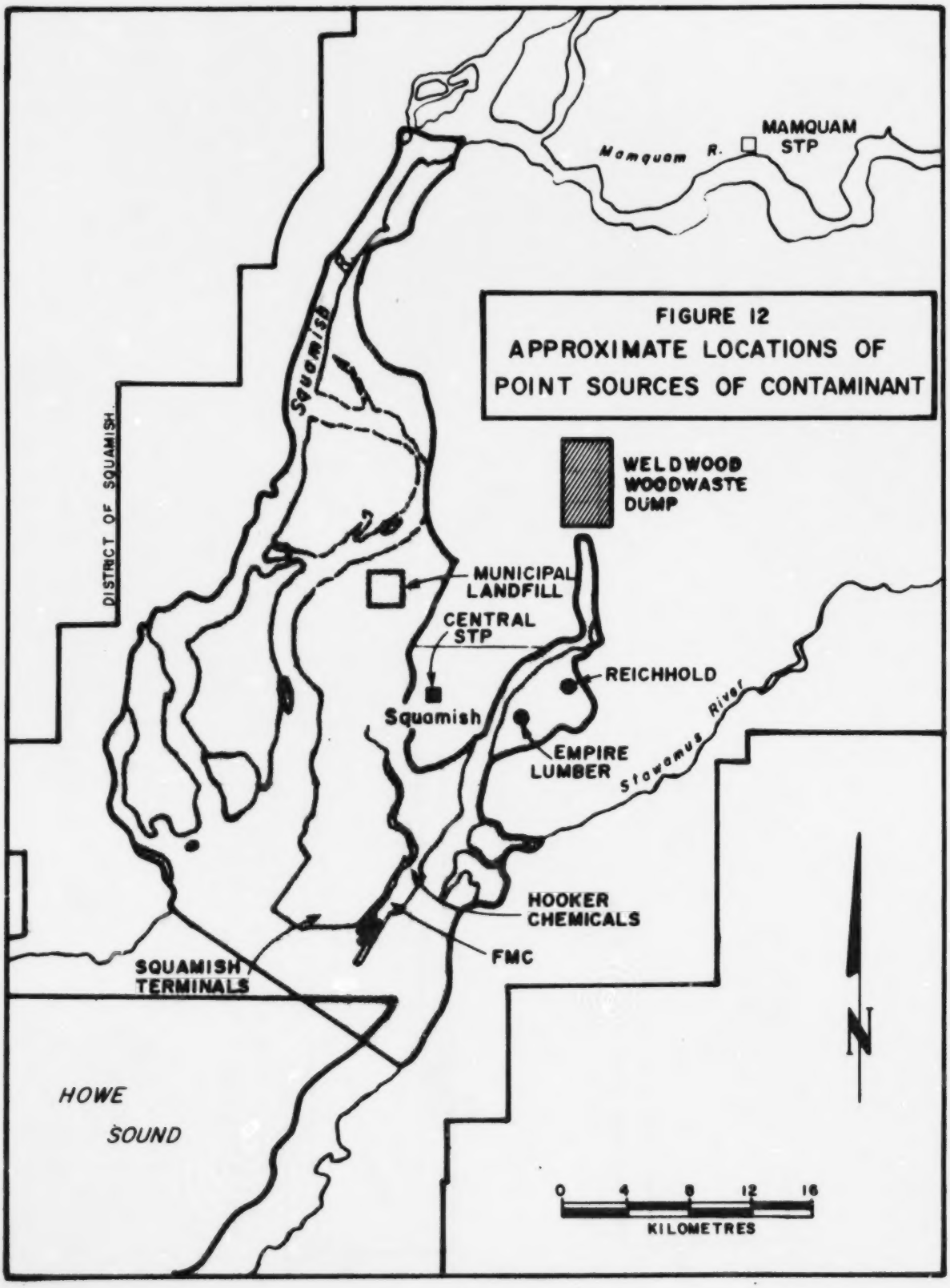


FIGURE 12
APPROXIMATE LOCATIONS OF
POINT SOURCES OF CONTAMINANT
MAMQUAM
STP
Mamquam R.
Squamish R.
DISTRICT OF SQUAMISH
WELDWOOD
WOODWASTE
DUMP
MUNICIPAL
LANDFILL
CENTRAL
STP
Squamish
REICHHOLD
EMPIRE
LUMBER
Stawamus River
HOOKER
CHEMICALS
FMC
SQUAMISH
TERMINALS
HOWE
SOUND
N
0 4 8 12 16
KILOMETRES

FIGURE 13.

SIMPLIFIED FLOW DIAGRAM FOR WELDWOOD'S SAWMILL PLANERMILL COMPLEX AT SQUAMISH.

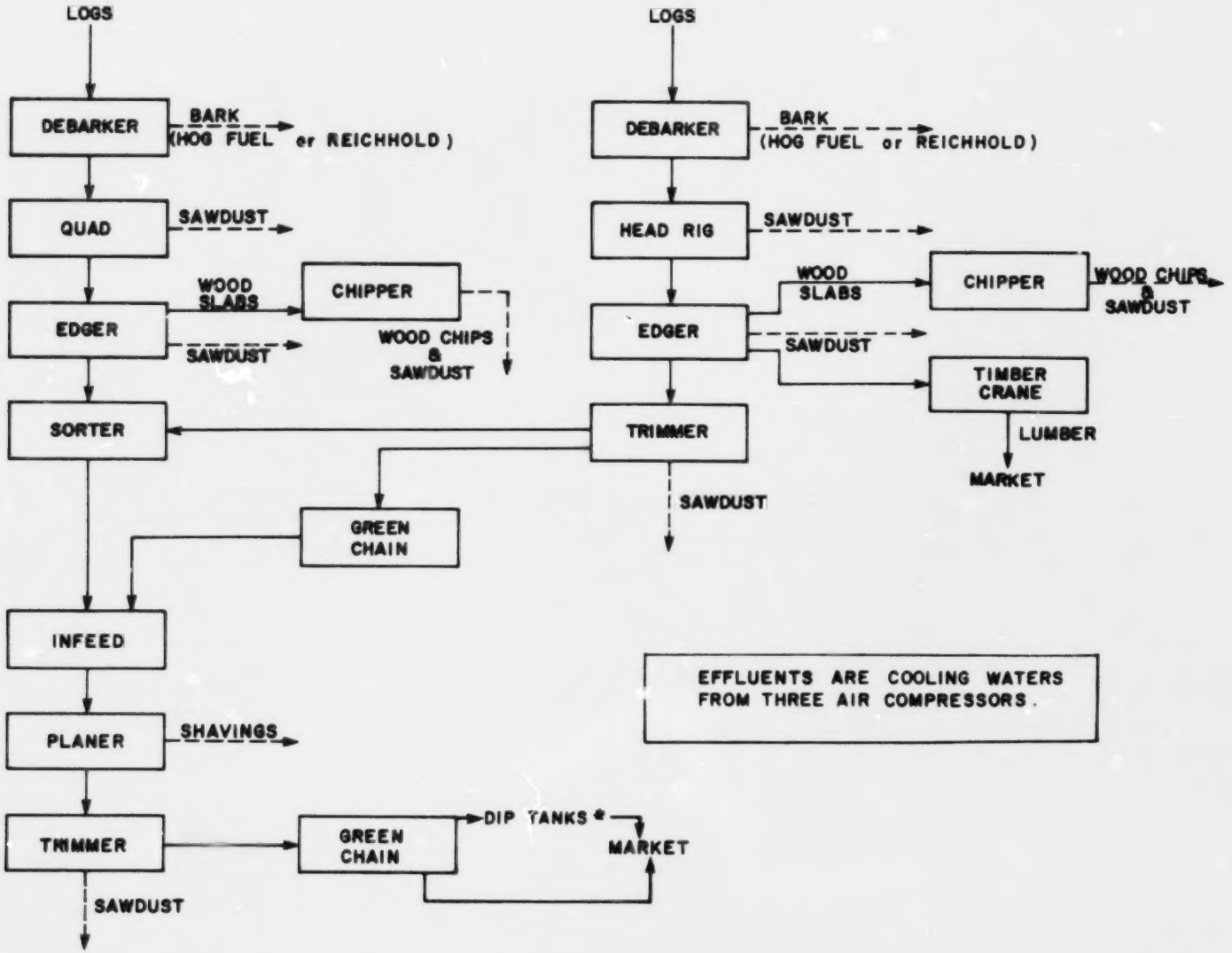
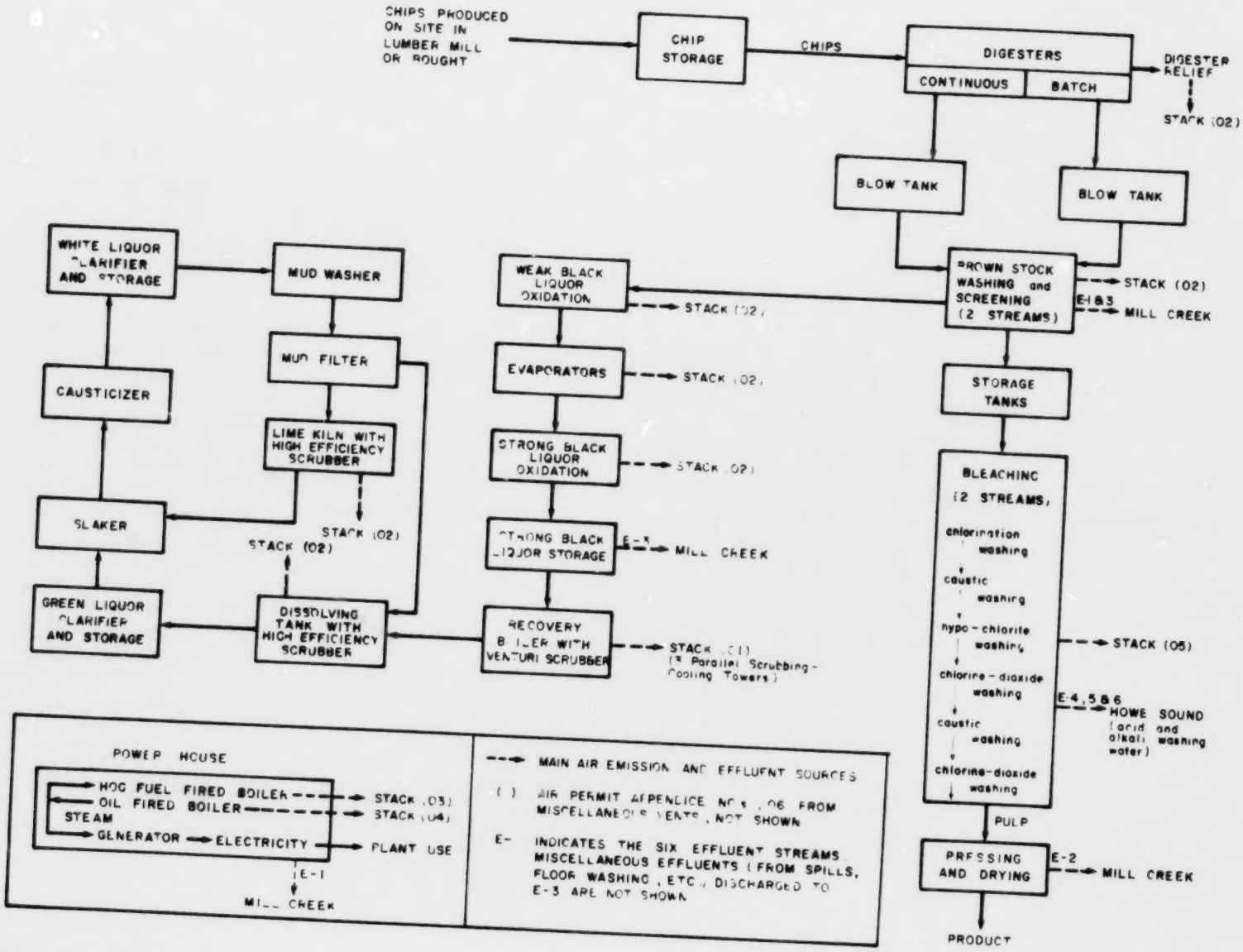


FIGURE 14 . SIMPLIFIED FLOW DIAGRAM FOR WOODFIBRE KRAFT PULP MILL (FORMERLY RAYONIER CANADA , LTD.)



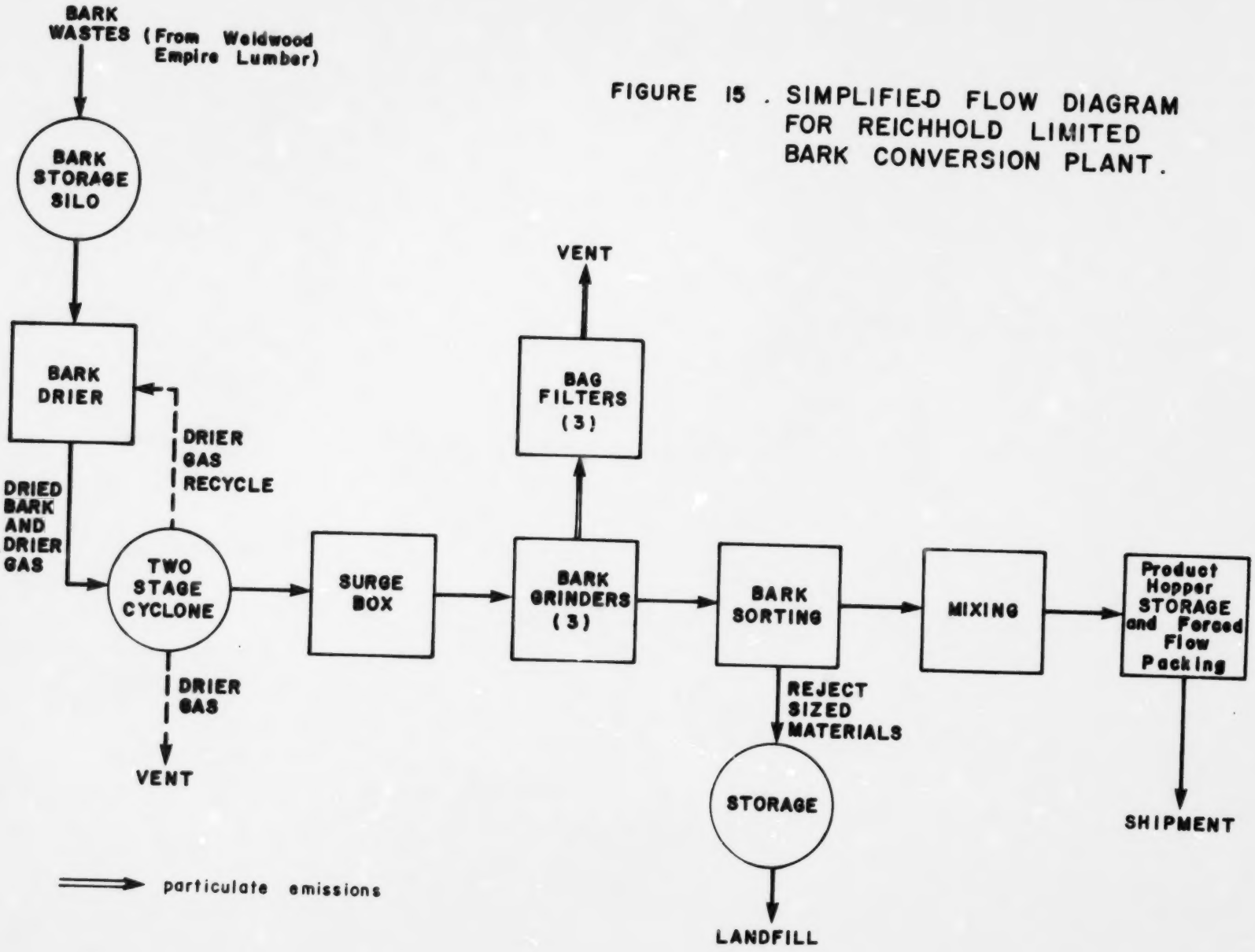
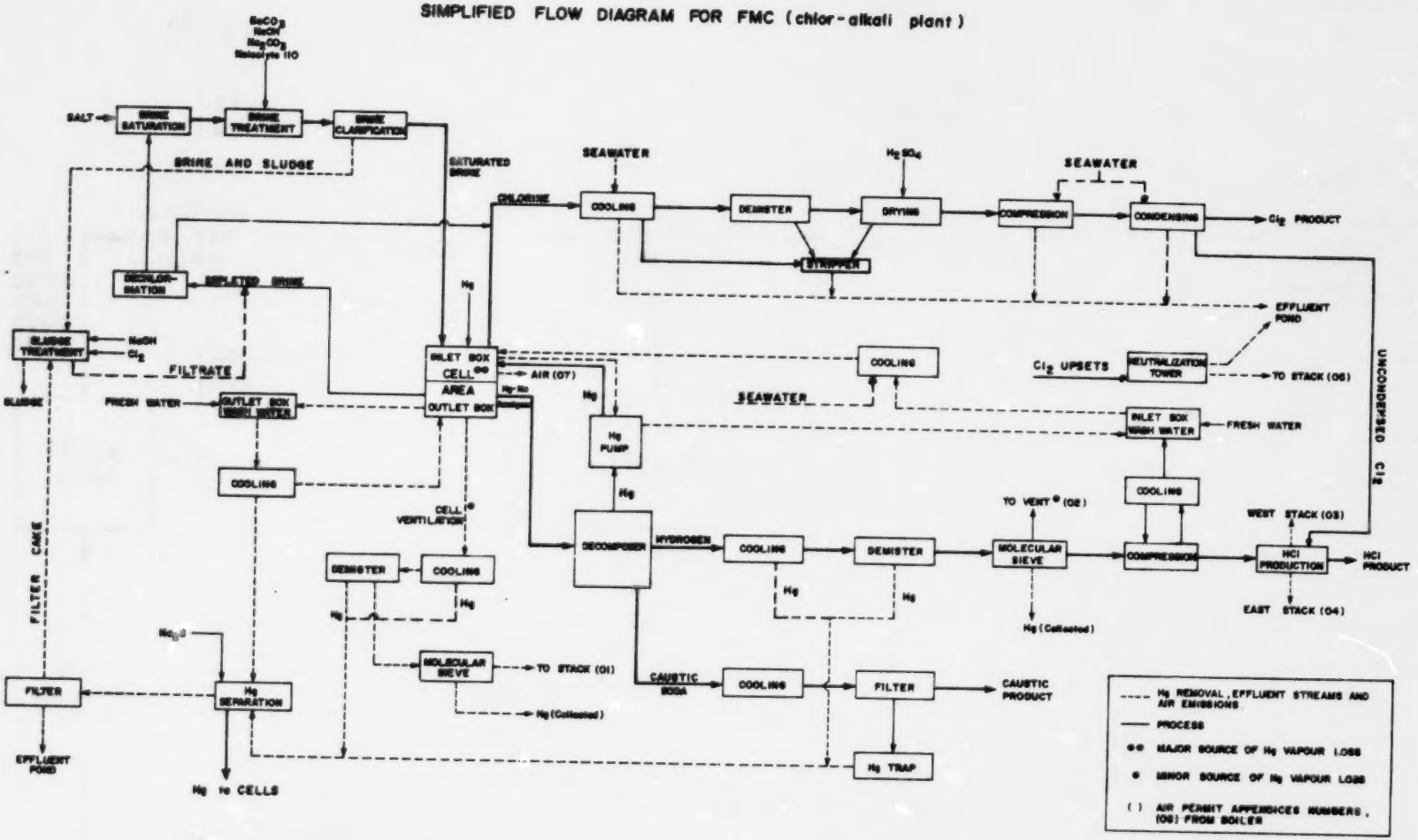


FIGURE 15 . SIMPLIFIED FLOW DIAGRAM FOR REICHHOLD LIMITED BARK CONVERSION PLANT.

FIGURE 16

SIMPLIFIED FLOW DIAGRAM FOR FMC (chlor-alkali plant)



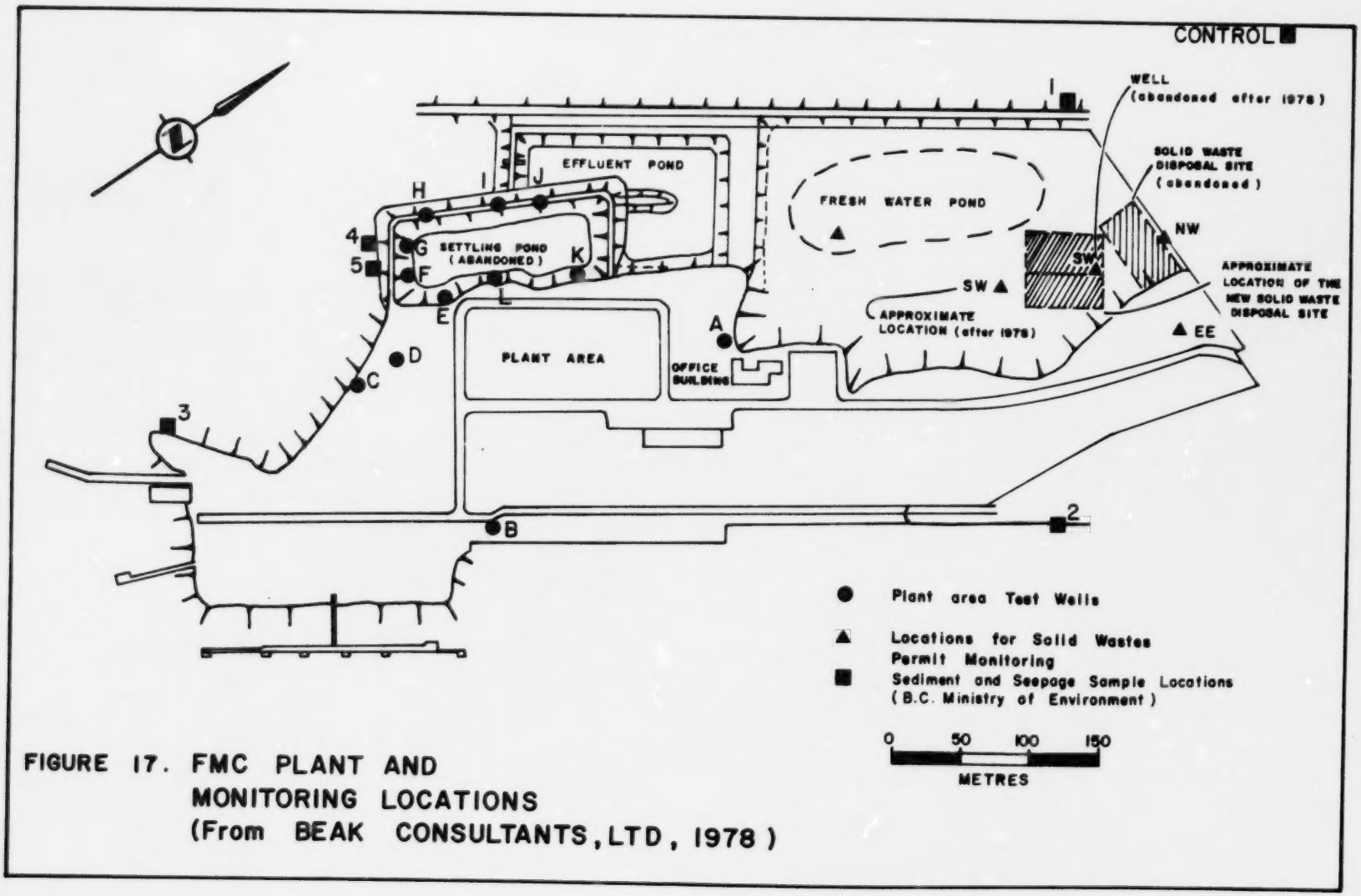
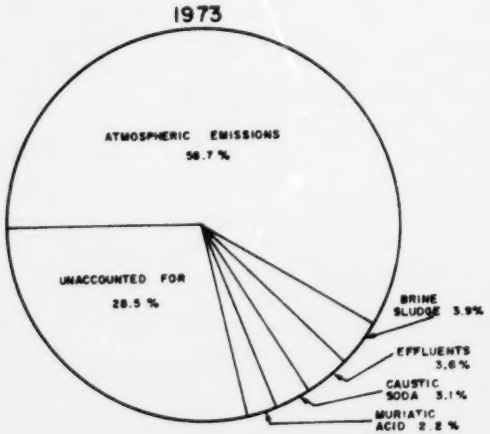


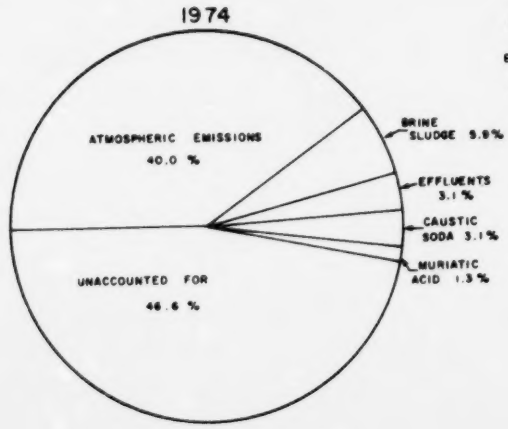
FIGURE 17. FMC PLANT AND MONITORING LOCATIONS (From BEAK CONSULTANTS, LTD, 1978)

FIGURE 18. FMC OF CANADA LTD. MERCURY BALANCES



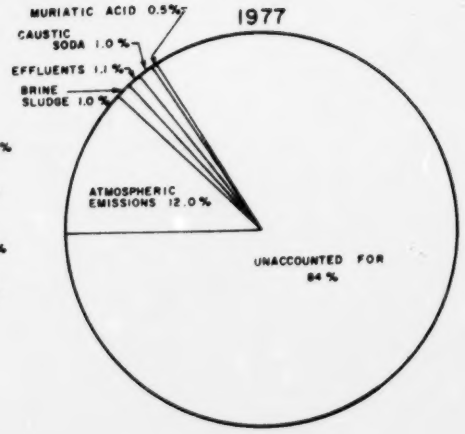
100 % = 789.0 kg

MERCURY LOST IN CHLORINE PRODUCTION = NEGLIGIBLE



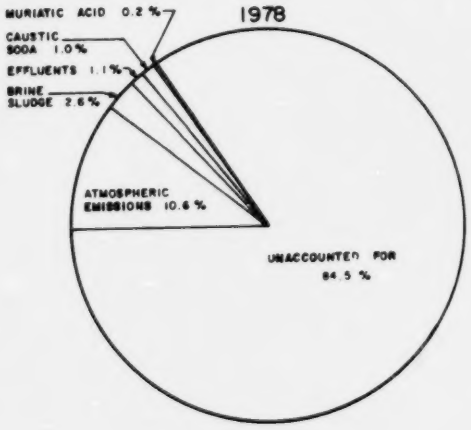
100 % = 828.0 kg

MERCURY LOST IN CHLORINE PRODUCTION = NEGLIGIBLE



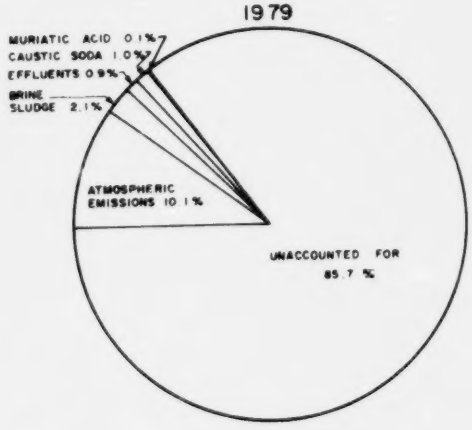
100 % = 2346.7 kg

MERCURY LOST IN CHLORINE PRODUCTION = NEGLIGIBLE



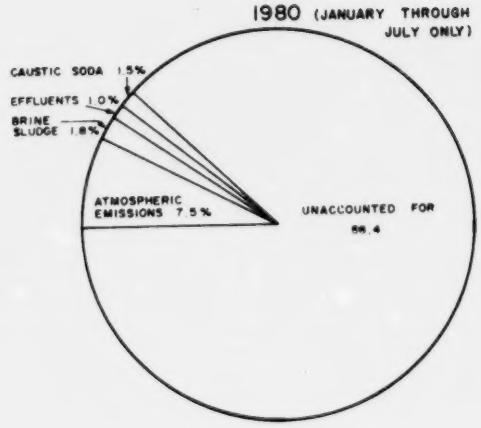
100 % = 3205.0 kg

MERCURY LOST IN CHLORINE PRODUCTION = NEGLIGIBLE



100 % = 3146.0 kg

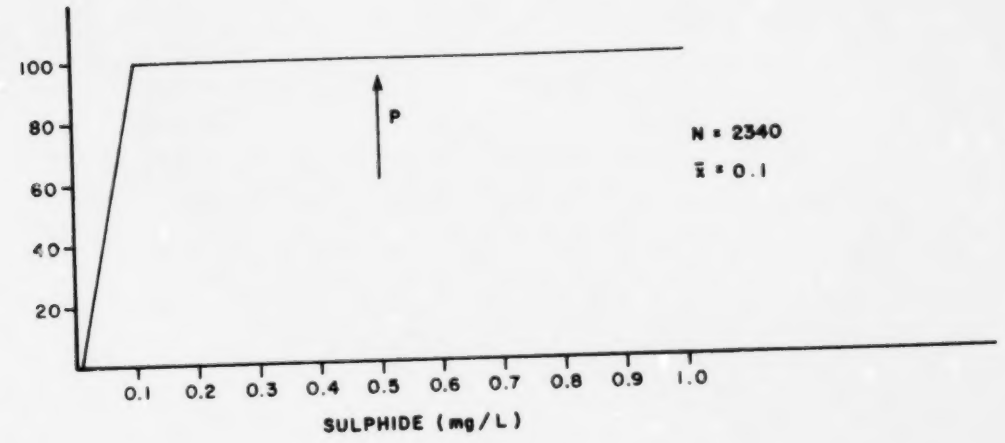
MERCURY LOST IN CHLORINE PRODUCTION = NEGLIGIBLE

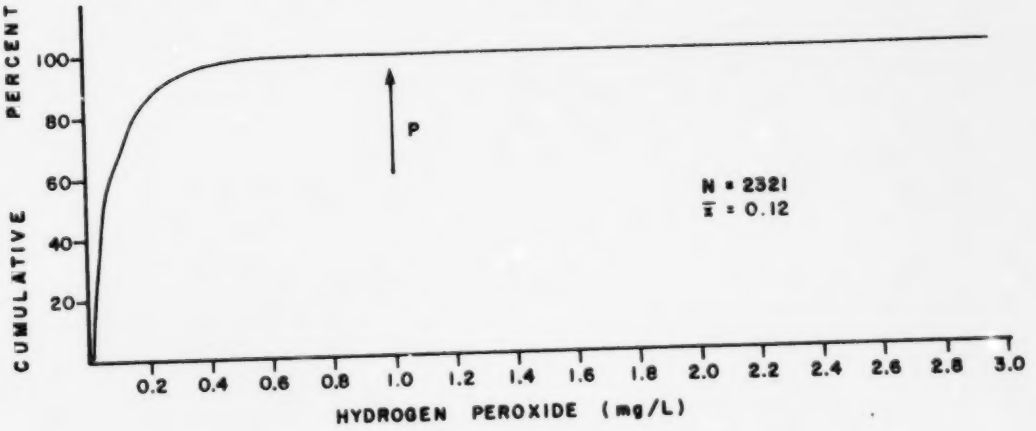


100 % = 1890.0 kg

MERCURY LOST IN CHLORINE AND MURIATIC ACID PRODUCTION = NEGLIGIBLE

FIGURE 19 . CUMULATIVE PERCENT OCCURENCE OF SULPHIDE, HYDROGEN PEROXIDE AND FLOW VALUES IN THE EFFLUENT FROM FMC (PE00138)(1973 through 1979)
P= Permit Level





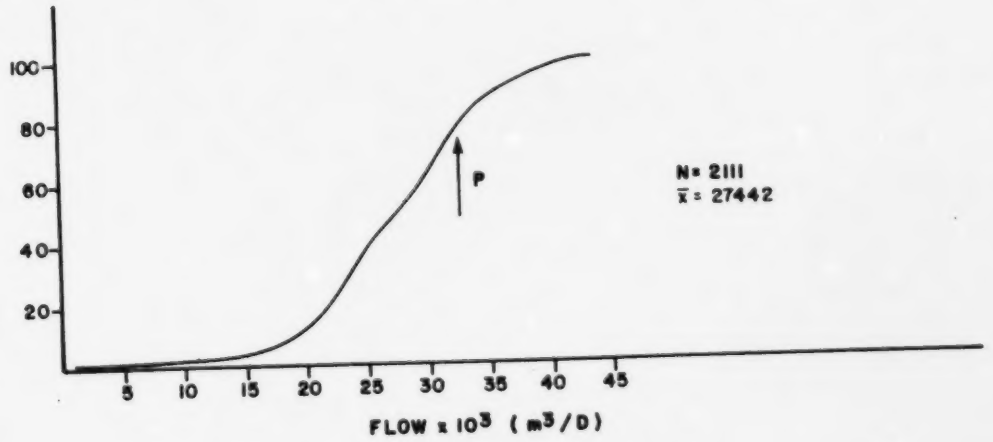


FIGURE 19 (continued)

. CUMULATIVE PERCENT OCCURENCE OF MERCURY, pH, RESIDUAL CHLORINE AND SUSPENDED SOLIDS VALUES IN THE EFFLUENT FROM FMC (PE00138) (1973 through 1979). P = Permit Level

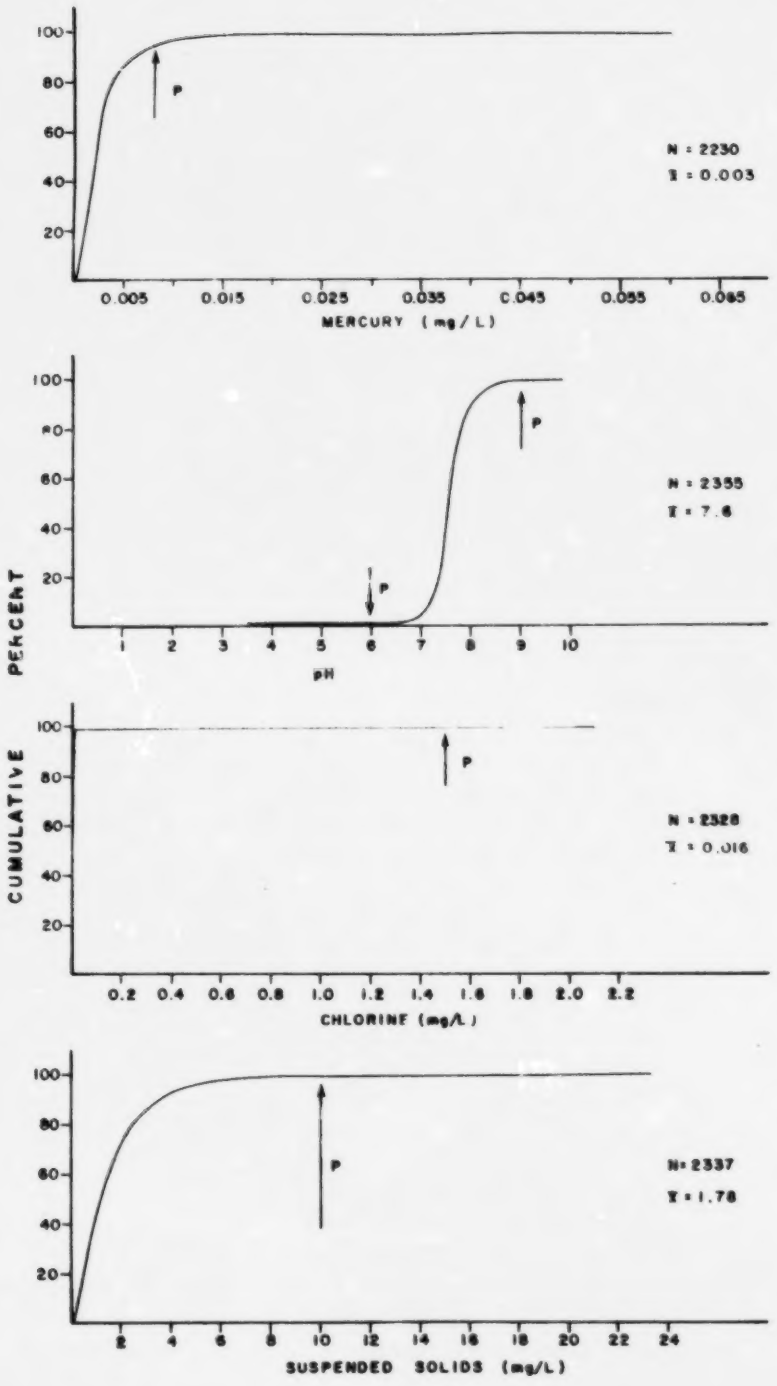
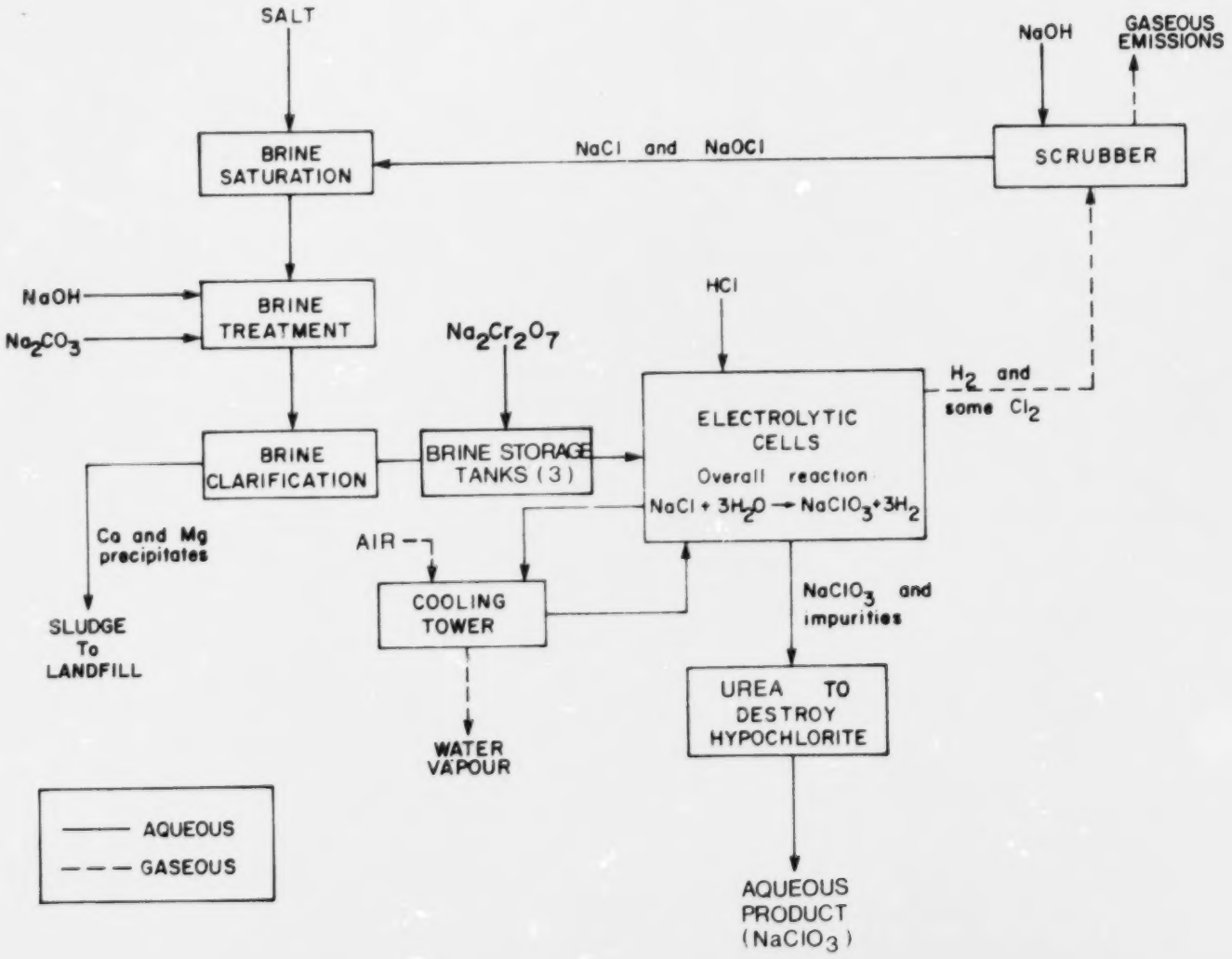


FIGURE 20
SIMPLIFIED FLOW DIAGRAM FOR CANADIANOXY (HOOKER) CHEMICALS
(sodium chlorate production)



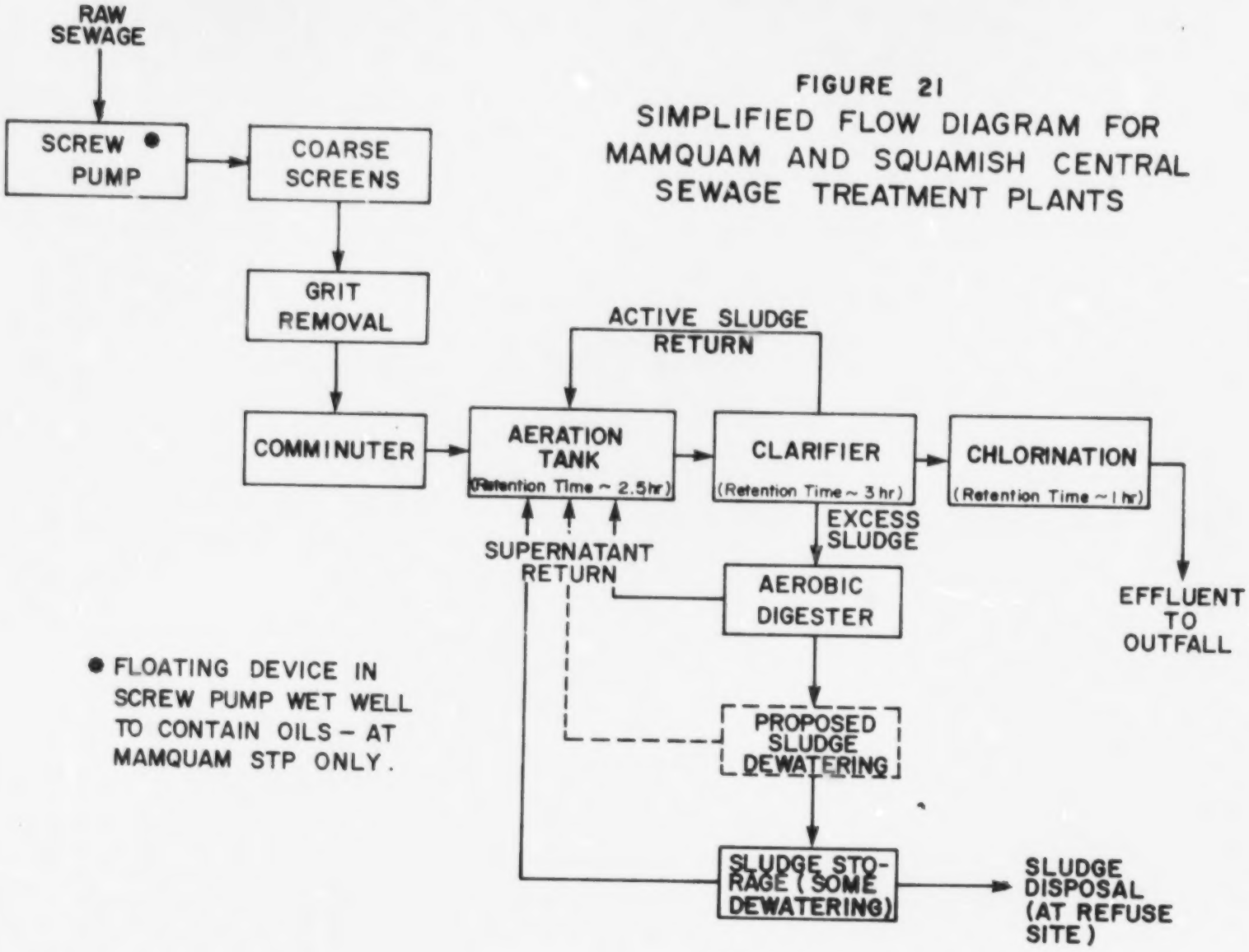


FIGURE 21
SIMPLIFIED FLOW DIAGRAM FOR MAMQUAM AND SQUAMISH CENTRAL SEWAGE TREATMENT PLANTS

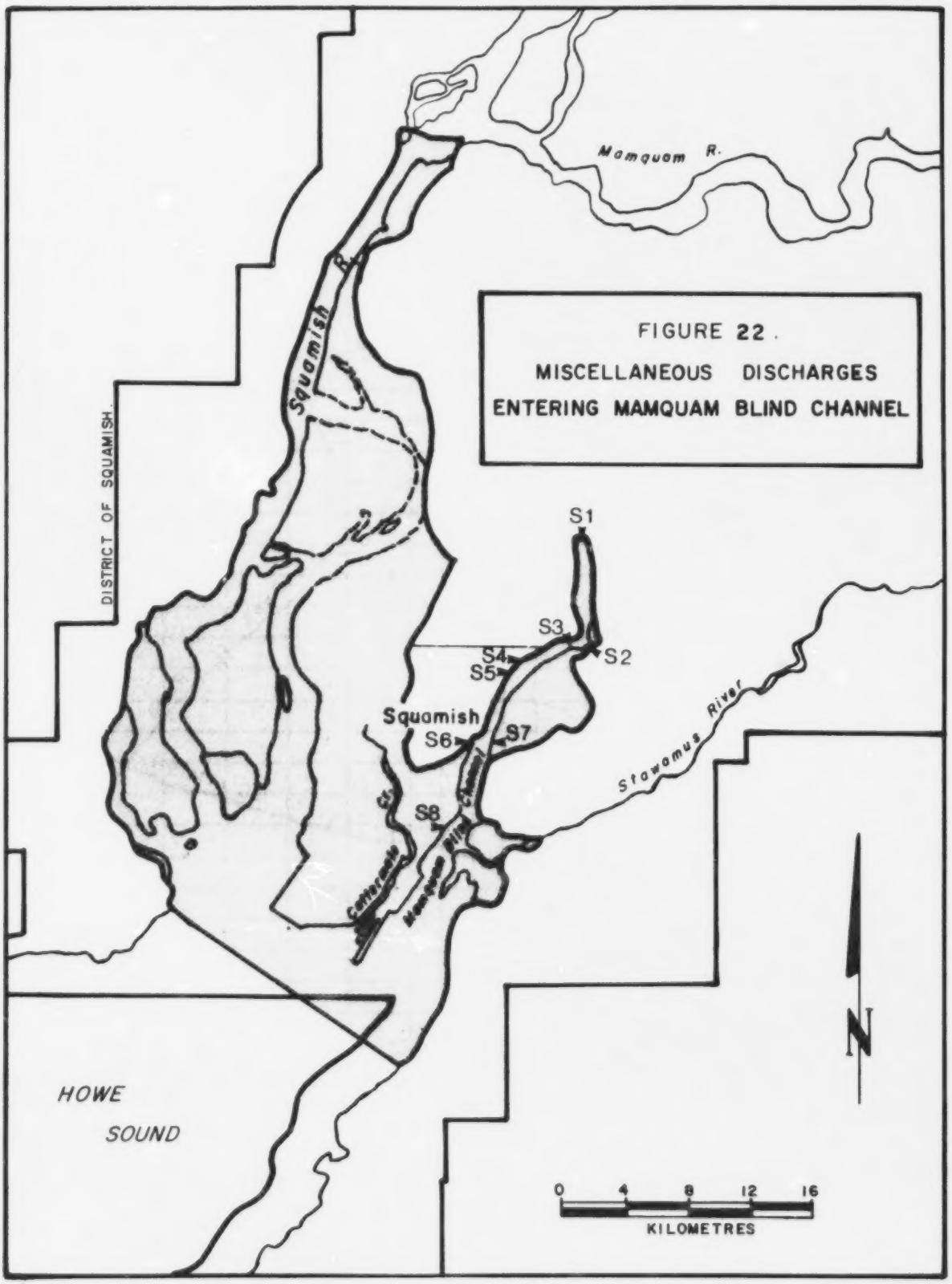


FIGURE 22.

MISCELLANEOUS DISCHARGES ENTERING MAMQUAM BLIND CHANNEL

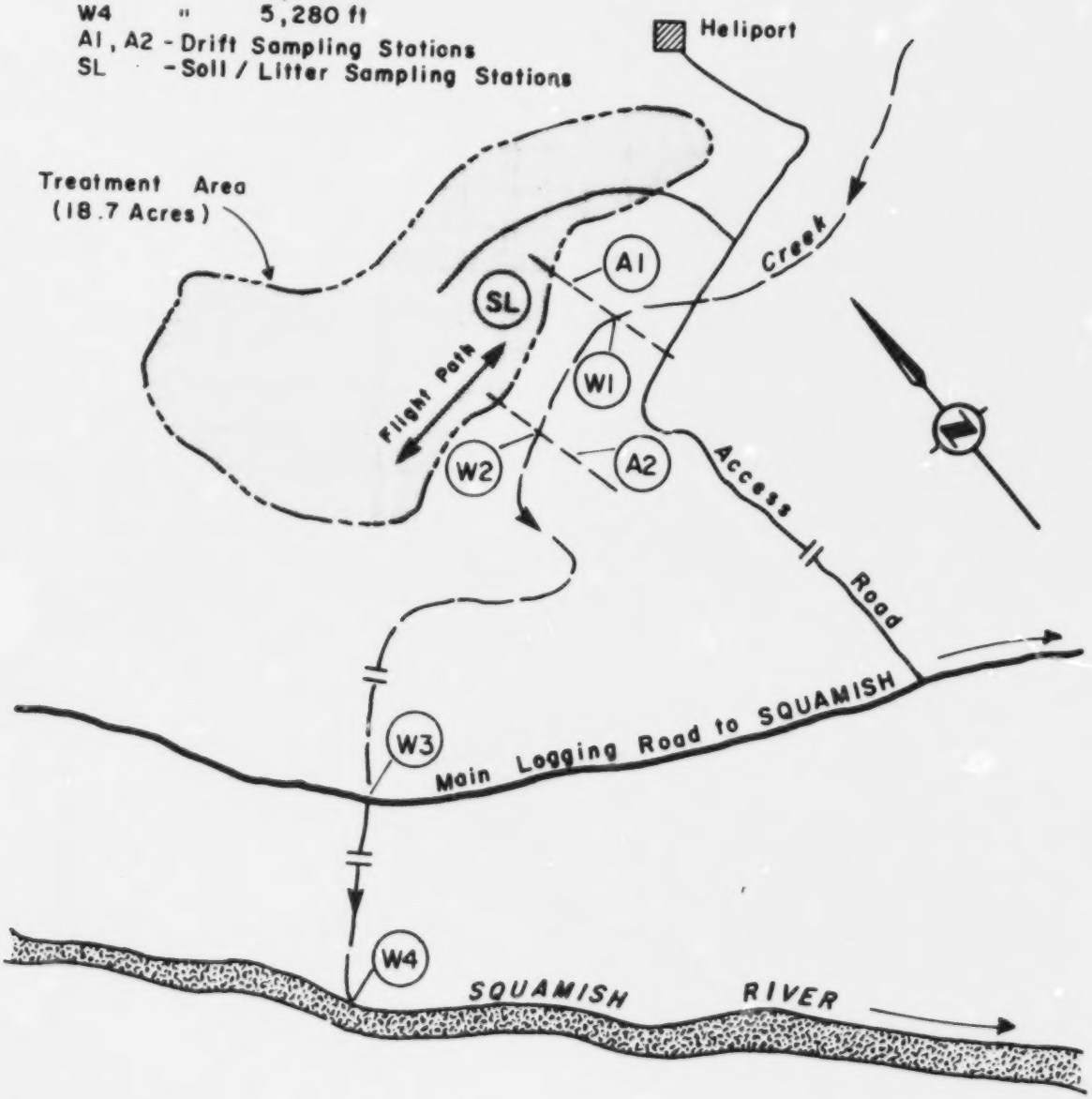


FIGURE 23 . DIAGRAM OF SPRAY PLOT , SQUAMISH , B.C.
(FROM WILSON and WAN , 1975)

FIGURE 24

AMBIENT AIR STATIONS AND AIR EMISSION PERMITS IN THE SQUAMISH RIVER ESTUARY.

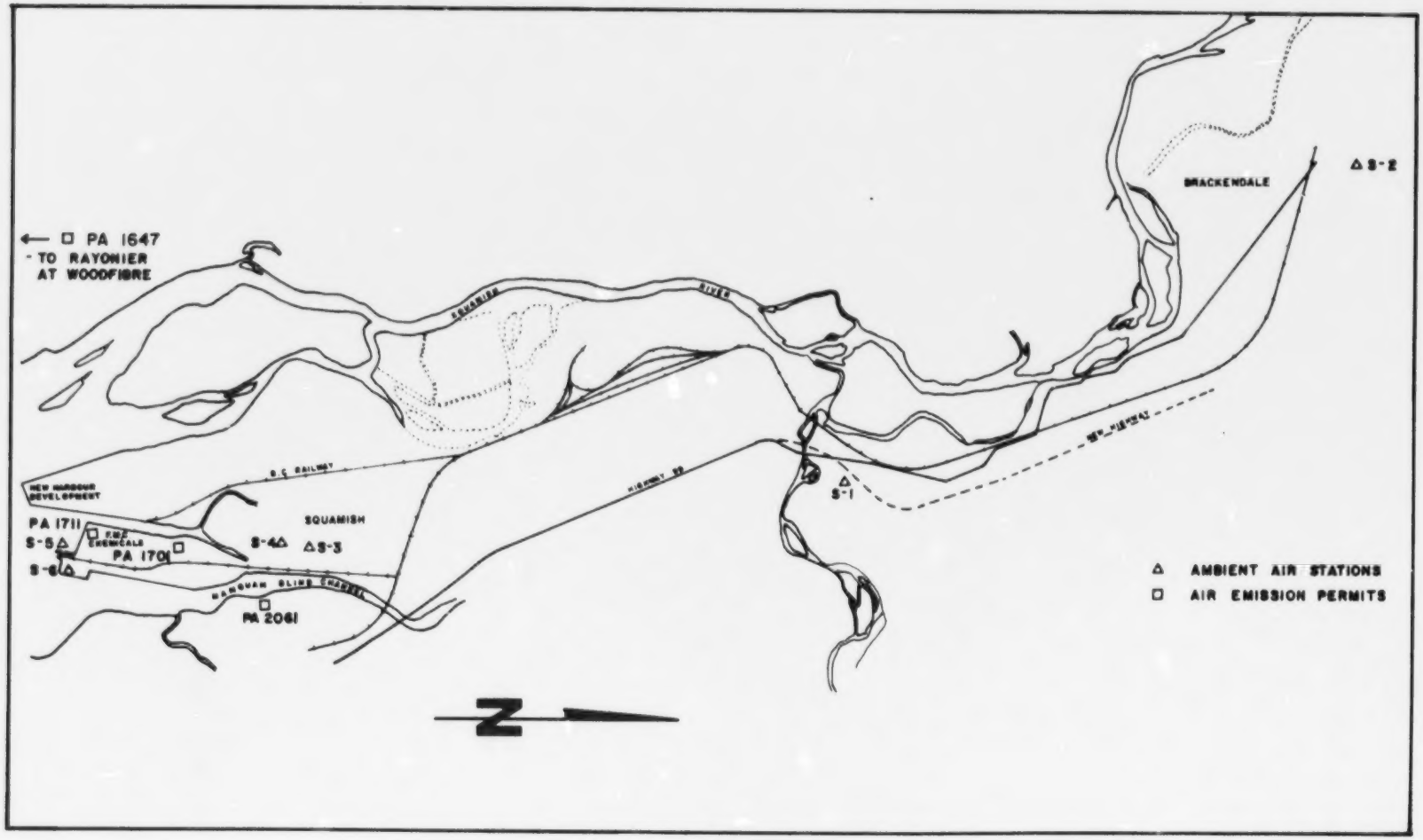
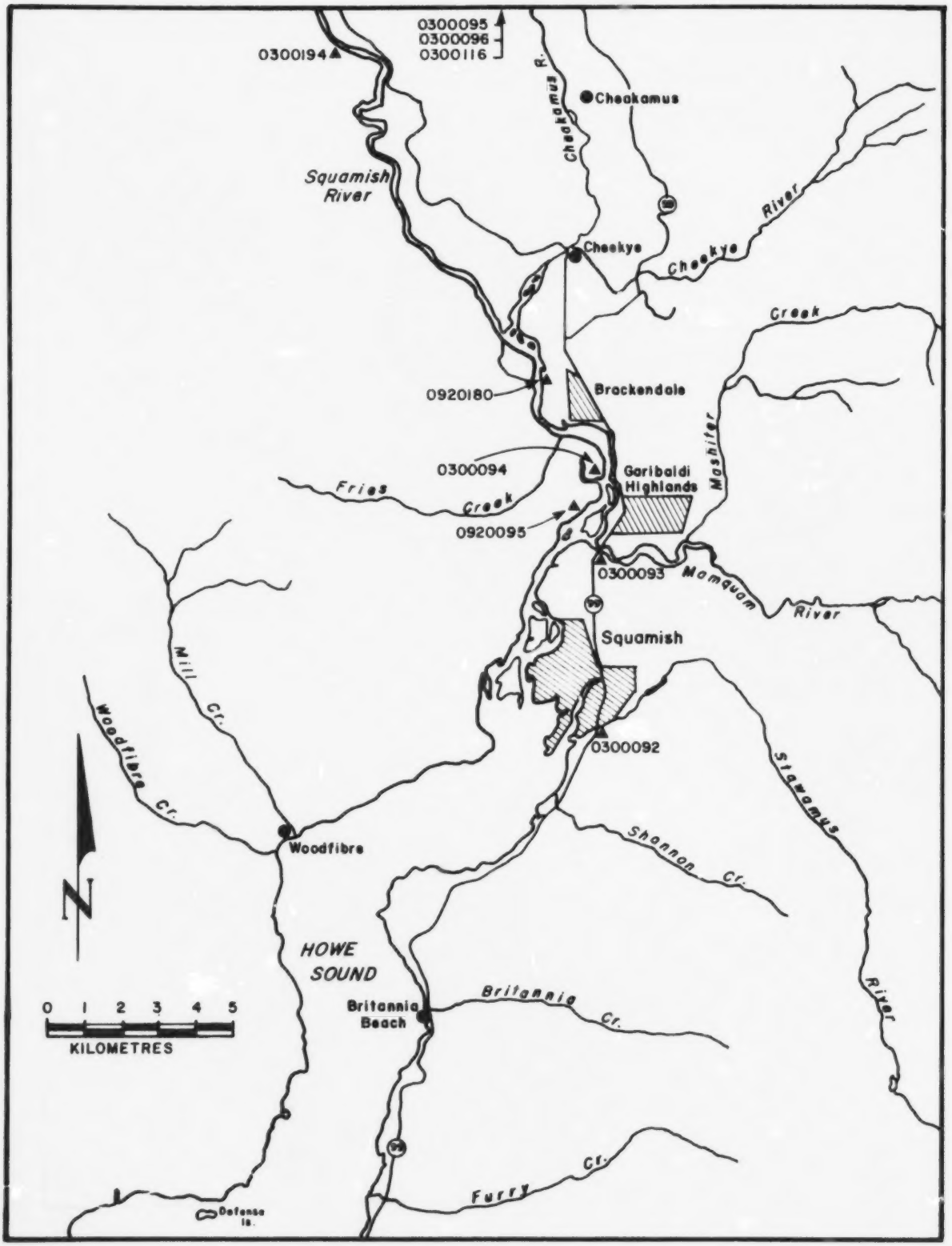


FIGURE 25. LOCATION OF MINISTRY OF ENVIRONMENT WATER QUALITY SAMPLING SITES IN THE SQUAMISH AREA



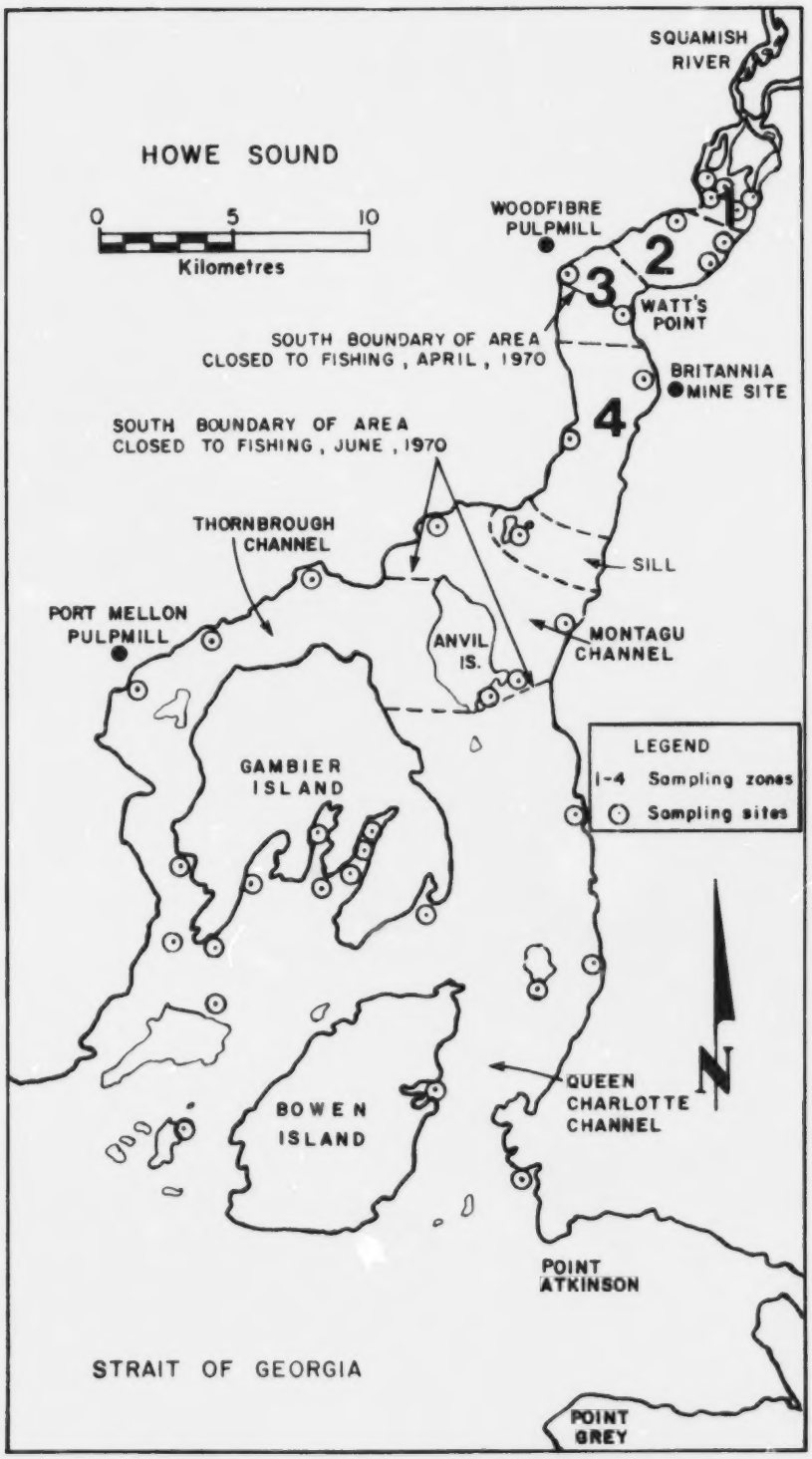


FIGURE 26. SAMPLING ZONES AND AREAS PREVIOUSLY CLOSED TO FISHING IN HOWE SOUND. (Adapted from Harbo and Birtwell, 1978)

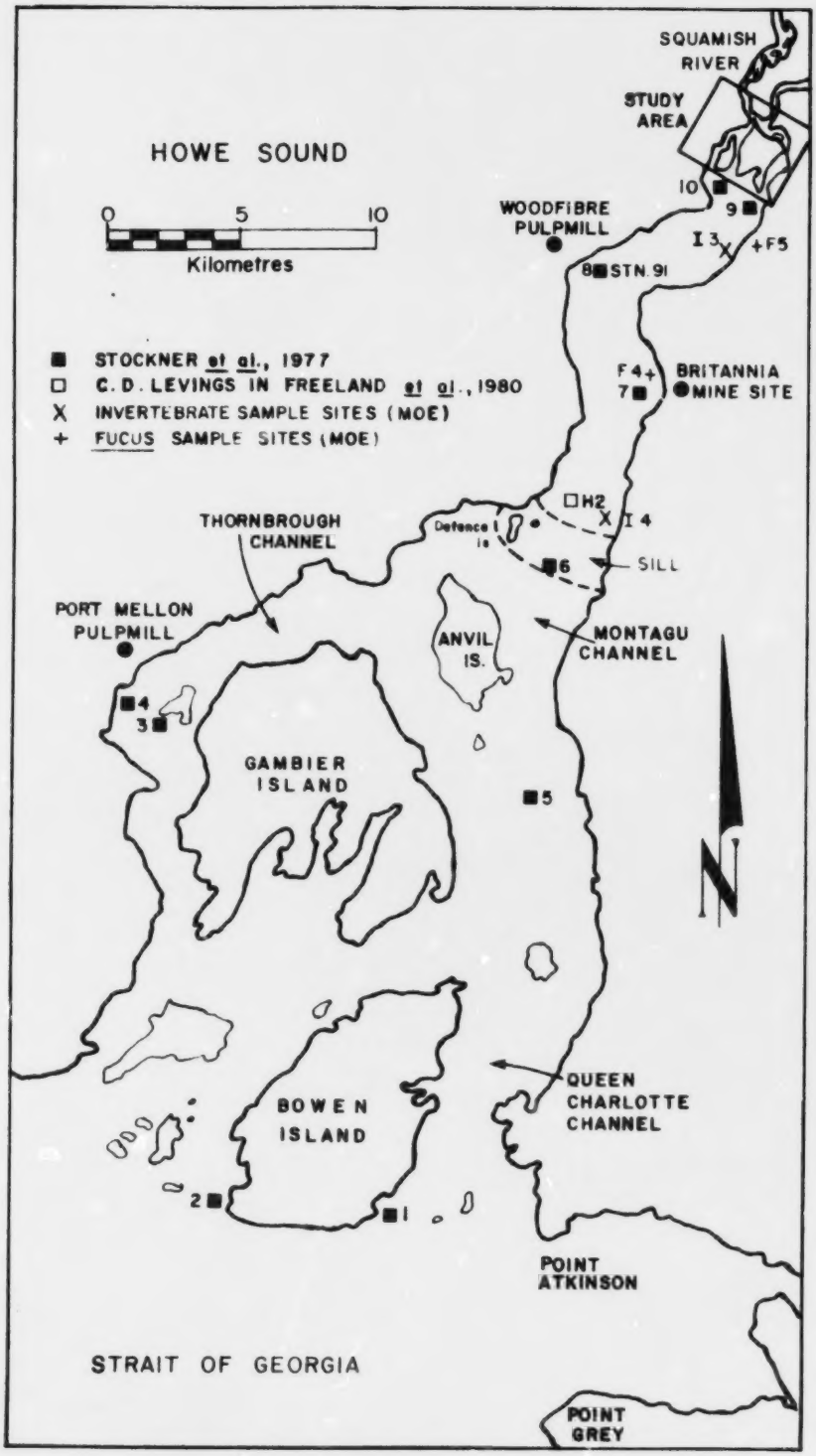
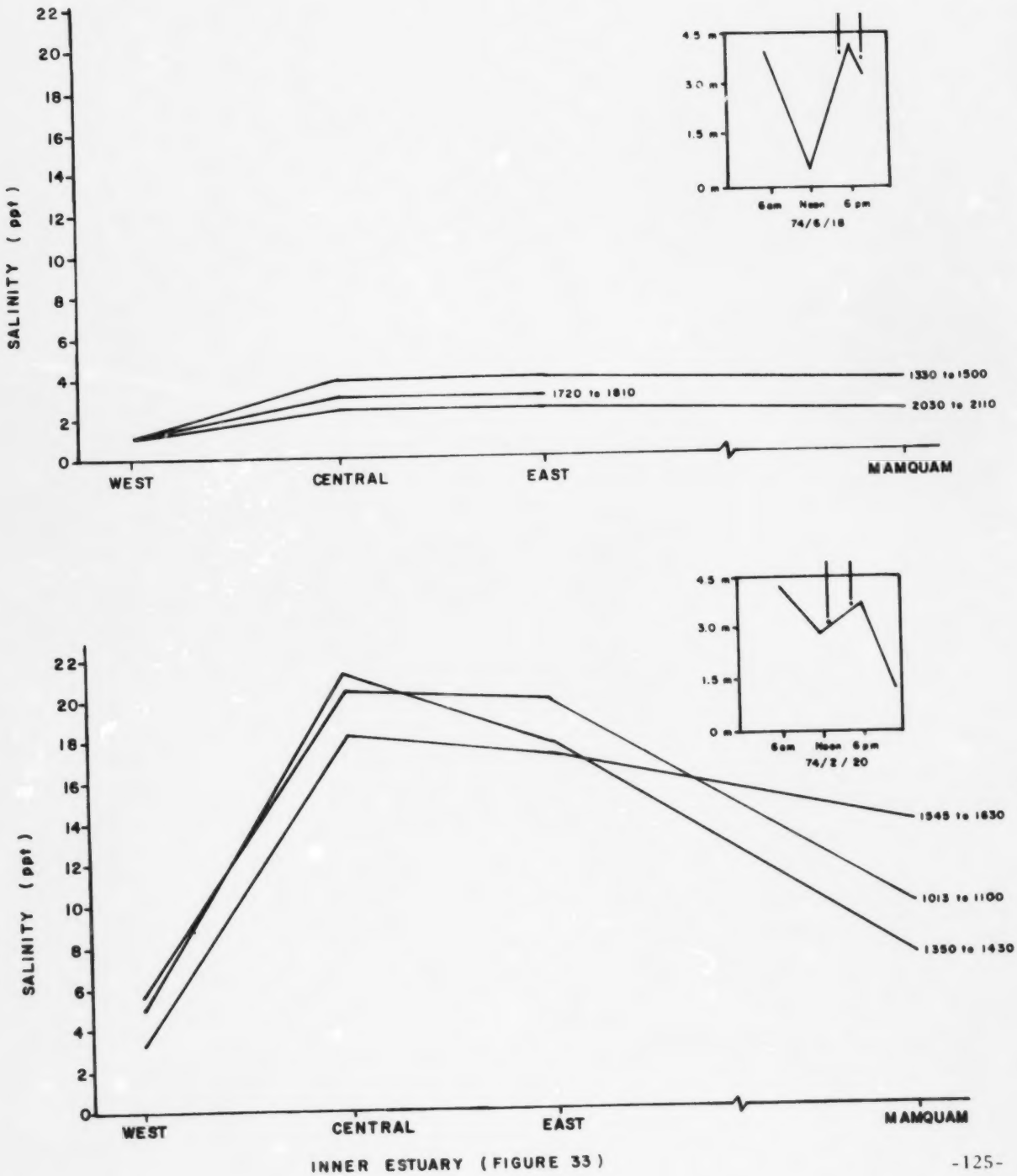


FIGURE 27 . MAP OF HOWE SOUND AND SQUAMISH ESTUARY SHOWING LOCATIONS OF SAMPLING STATIONS.

FIGURE 28.

SALINITY DISTRIBUTION ACROSS THE ESTUARY.
(From LEVINGS, 1980.)



INNER ESTUARY (FIGURE 33)

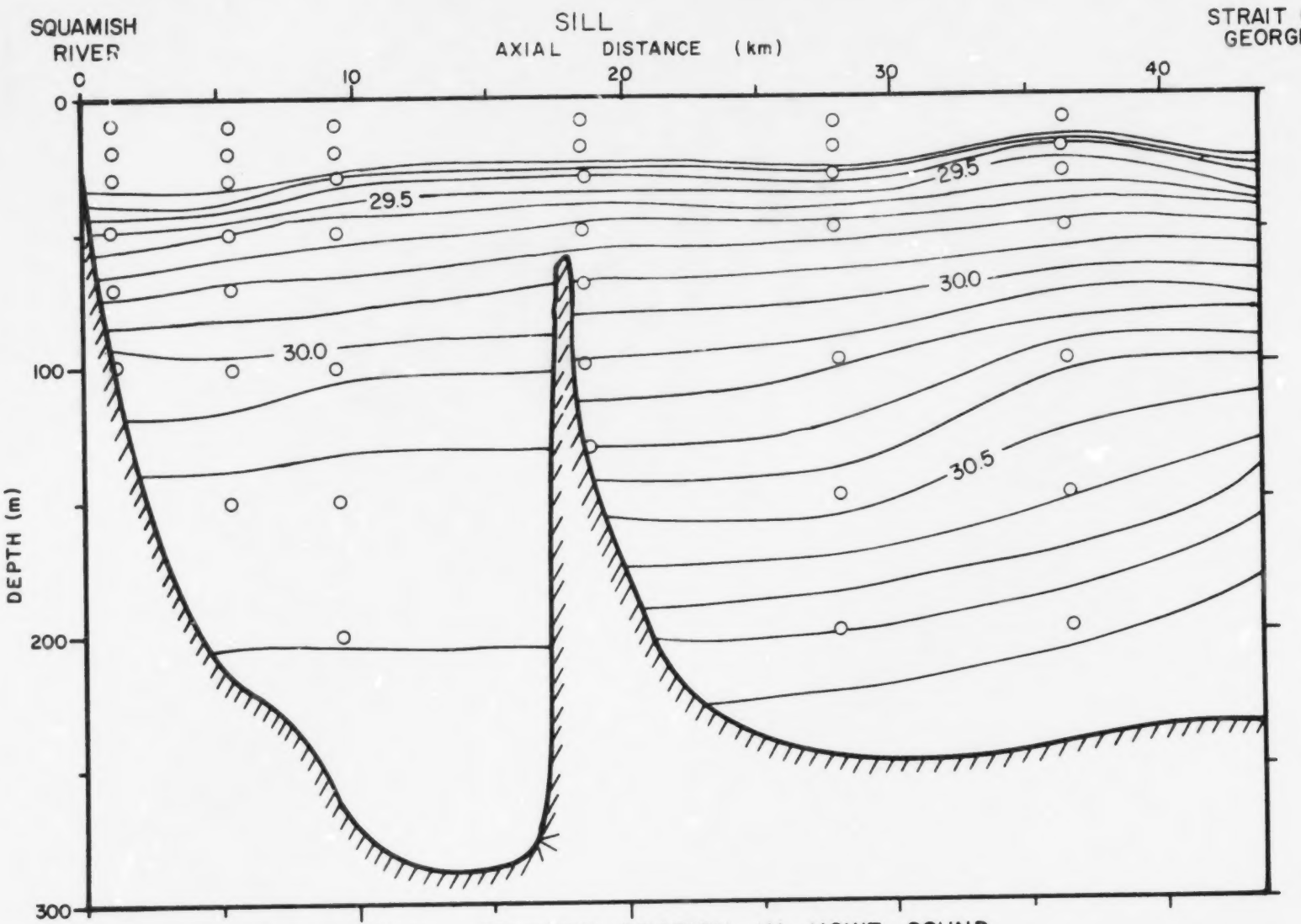


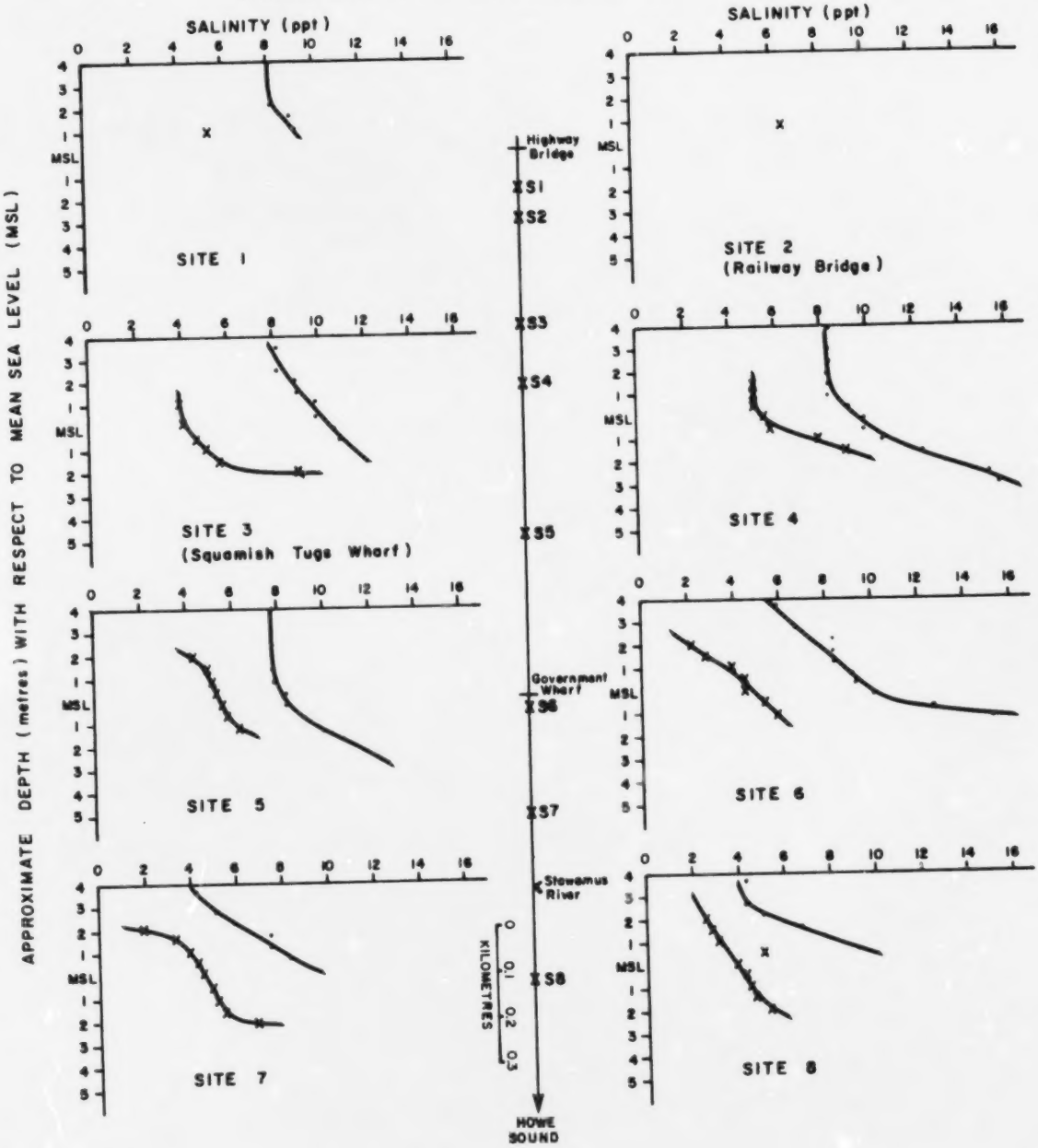
FIGURE 29 . AXIAL SALINITY SECTION IN HOWE SOUND, SEPTEMBER 29, 1968. (FROM BELL, 1973).

FIGURE 30

SALINITY PROFILES
MAMQUAM BLIND CHANNEL

X LOW TIDE
. HIGH TIDE

(SAMPLING LOCATIONS INDICATED IN FIGURE 31)



SAMPLED BY AQUATIC STUDIES BRANCH , MINISTRY OF ENVIRONMENT , JUNE 1980

FIGURE 31
SAMPLING LOCATIONS
JUNE 1980 FIELD SURVEY
(SAMPLED BY AQUATIC STUDIES BRANCH , MINISTRY OF ENVIRONMENT)

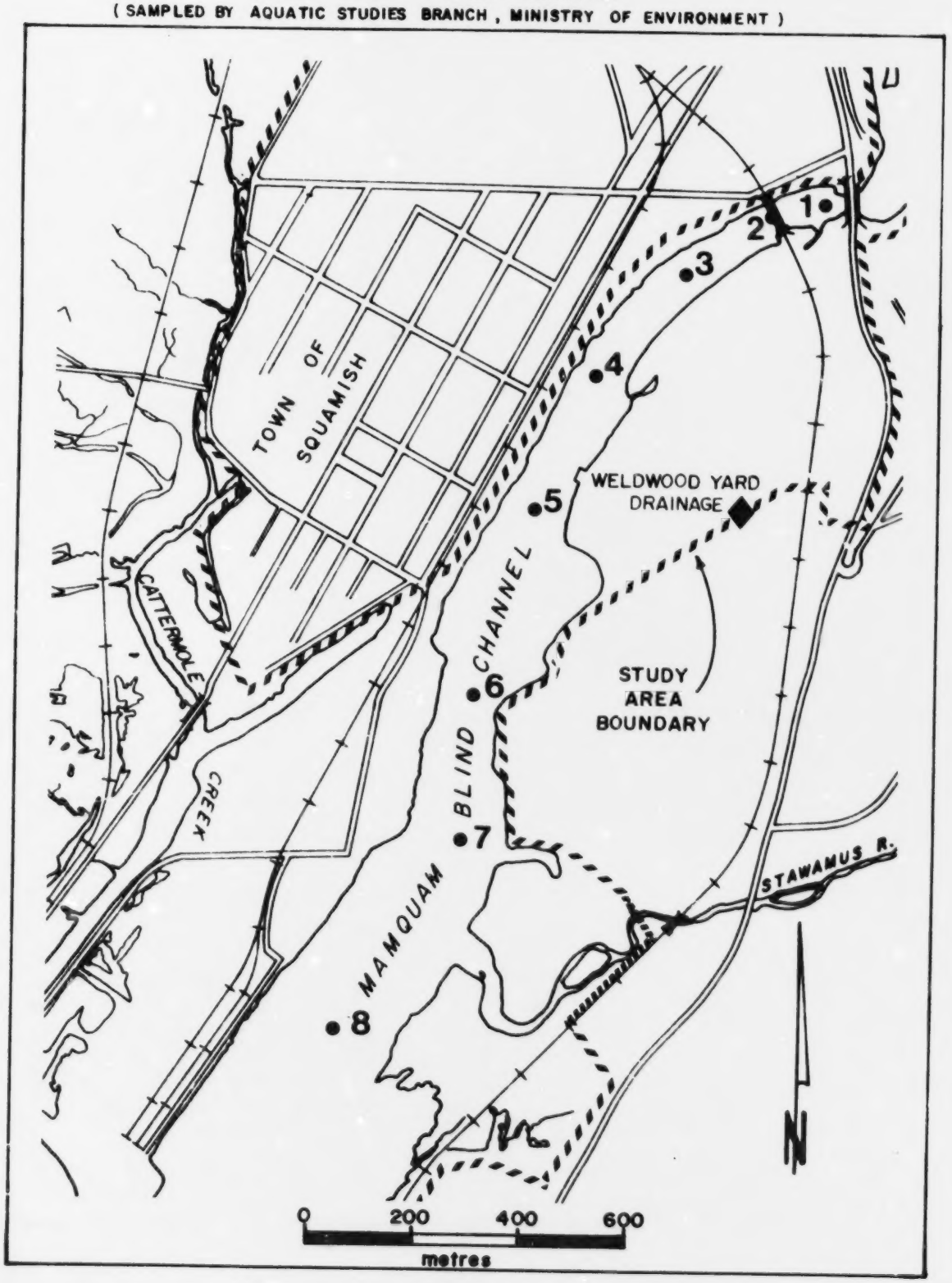
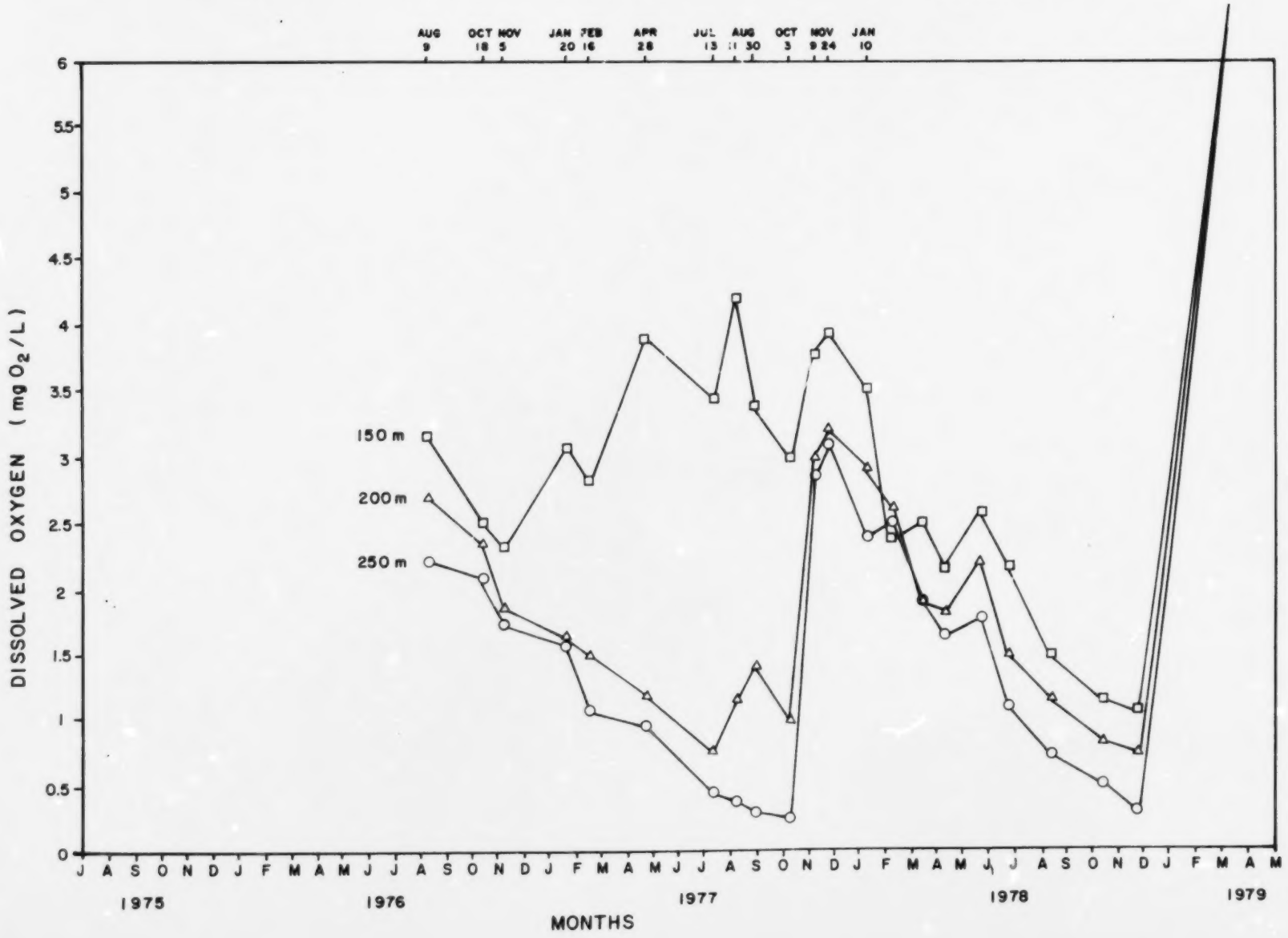


FIGURE 32 .

DISSOLVED OXYGEN CONCENTRATIONS IN BOTTOM WATER NORTH OF SILL IN HOWE SOUND (From C.D. LEVINGS in FREELAND et al., 1980)



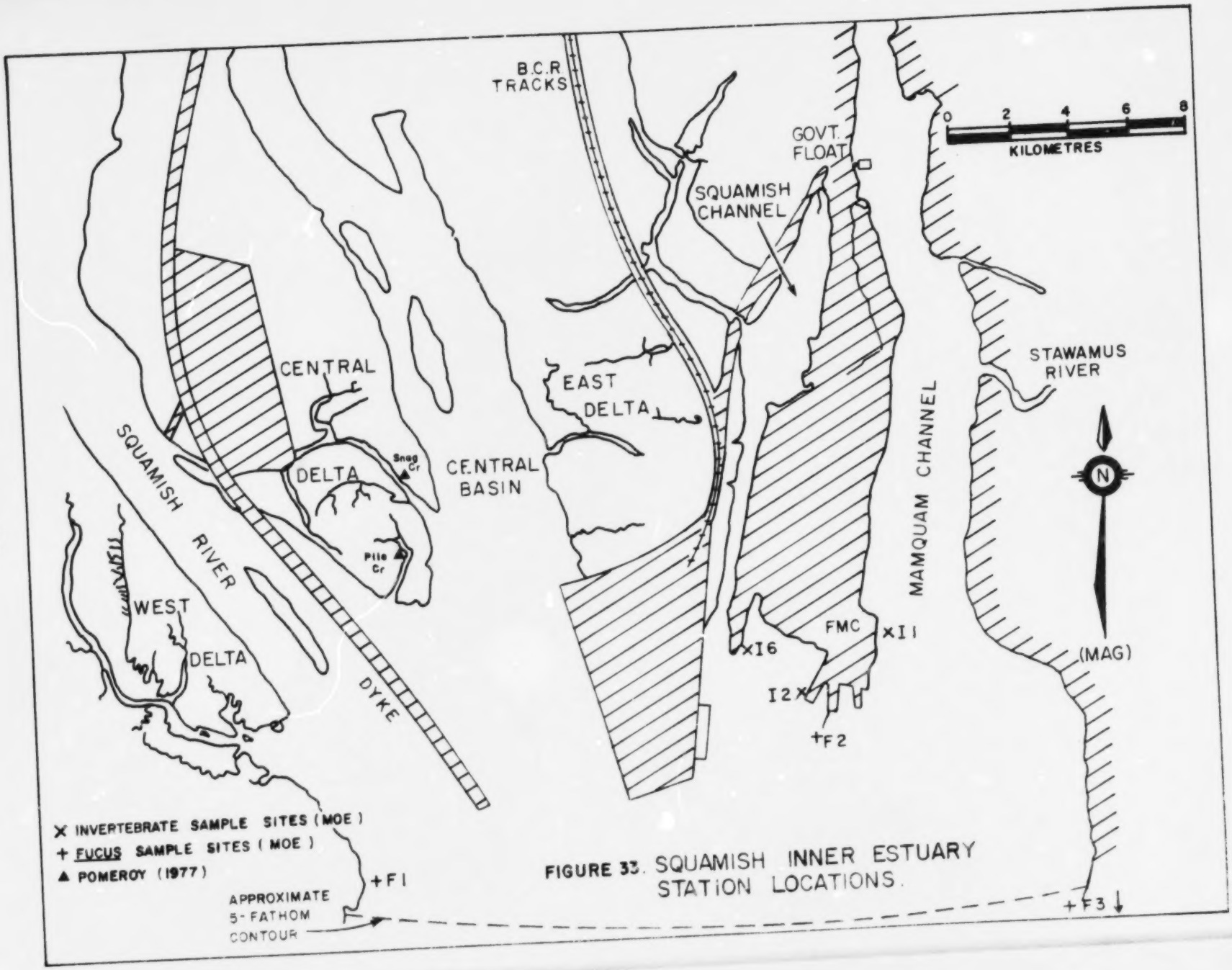


FIGURE 33. SQUAMISH INNER ESTUARY STATION LOCATIONS.

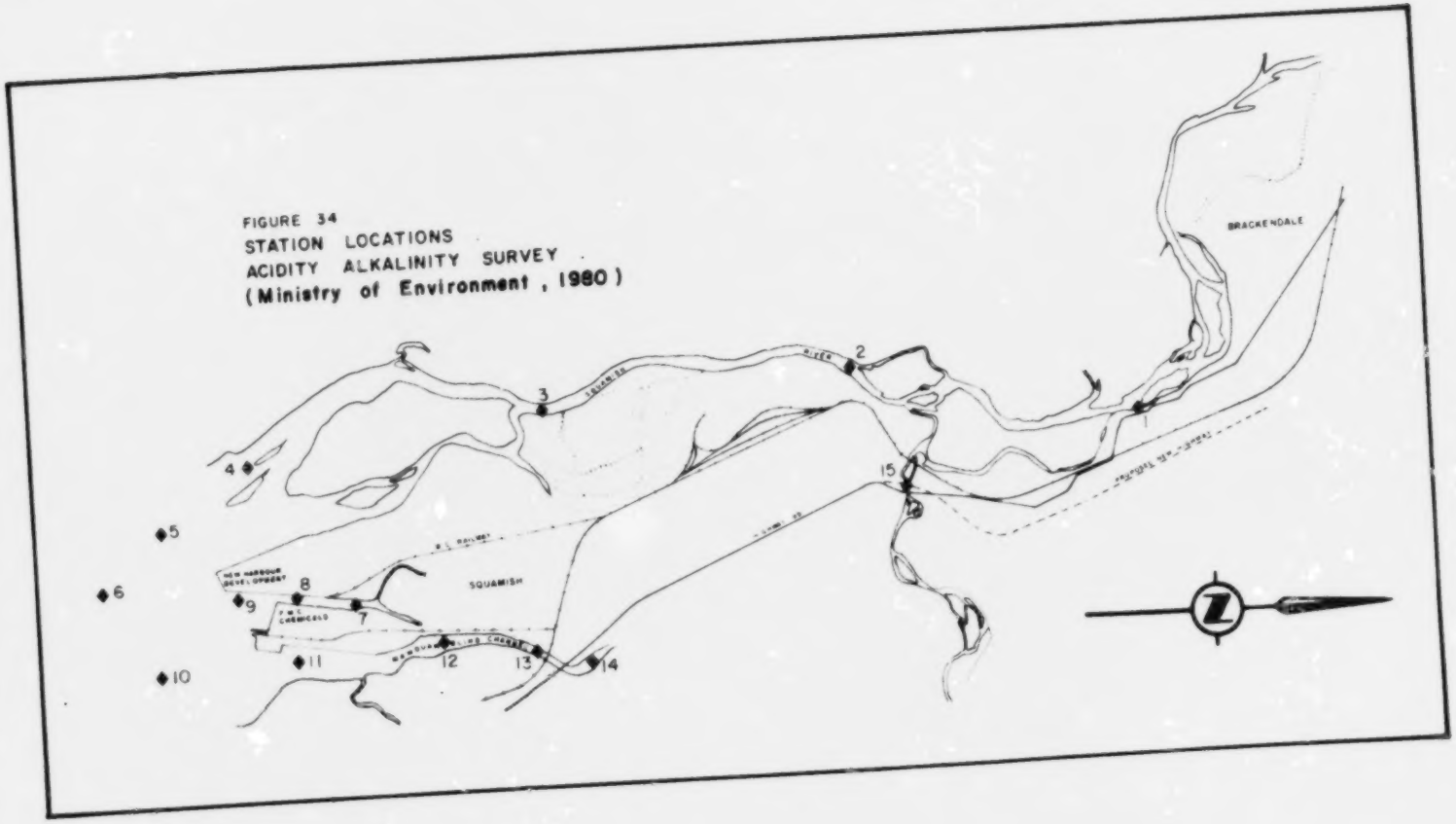


FIGURE 34
STATION LOCATIONS
ACIDITY ALKALINITY SURVEY
(Ministry of Environment, 1980)

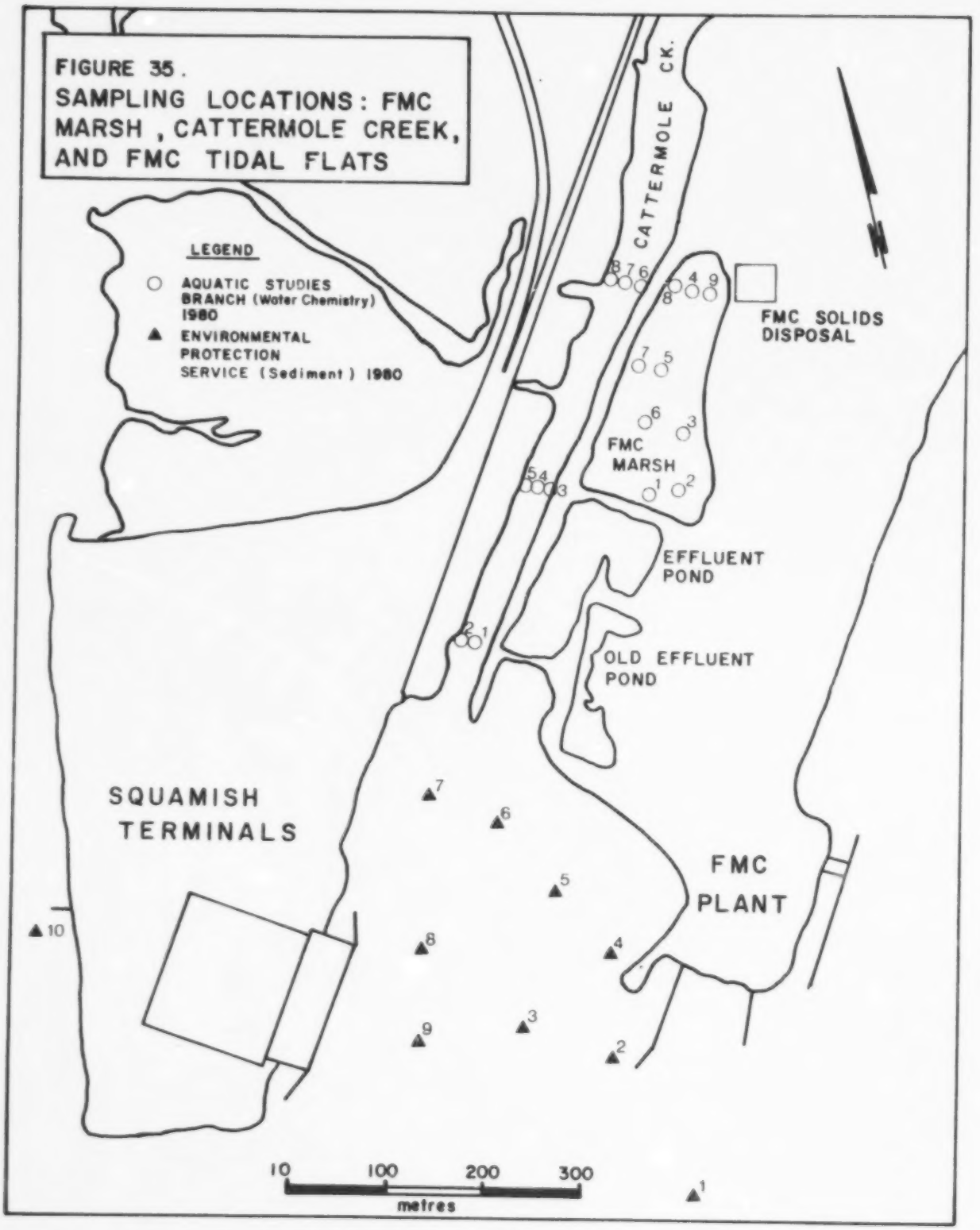


FIGURE 35.
SAMPLING LOCATIONS: FMC MARSH, CATTERMOLE CREEK, AND FMC TIDAL FLATS
LEGEND
AQUATIC STUDIES BRANCH (Water Chemistry) 1980
ENVIRONMENTAL PROTECTION SERVICE (Sediment) 1980
CATTERMOLE CK.
FMC SOLIDS DISPOSAL
FMC MARSH
EFFLUENT POND
OLD EFFLUENT POND
SQUAMISH TERMINALS
FMC PLANT
10
100
200
300
metres

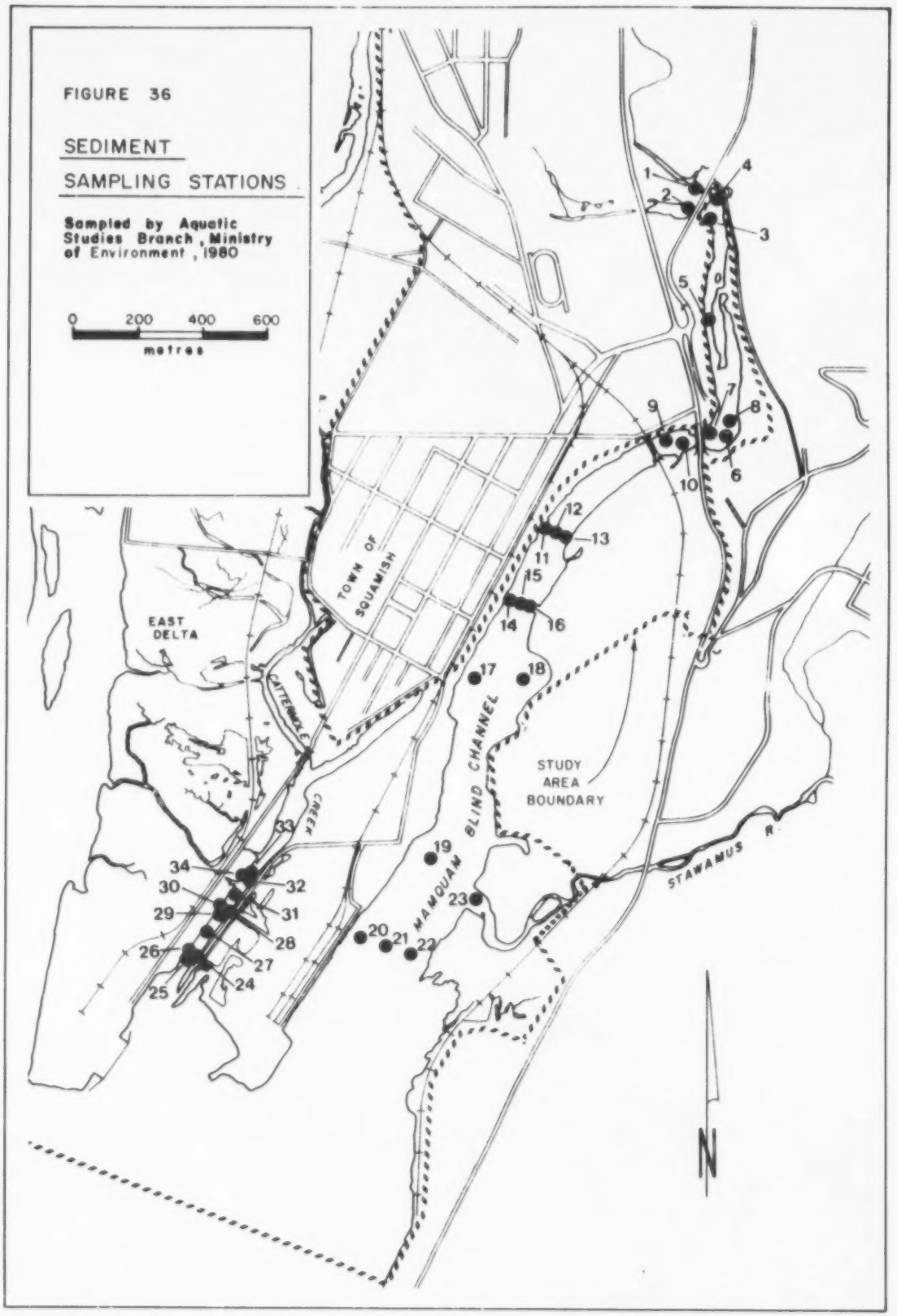


FIGURE 36
SEDIMENT
SAMPLING STATIONS
Sampled by Aquatic Studies Branch, Ministry of Environment, 1980
0 200 400 600
metres
TOWN OF SQUAMISH
EAST DELTA
CATTERMOLE CREEK
MAMQUAM BLIND CHANNEL
STUDY AREA BOUNDARY
STAWAMUS R.
N

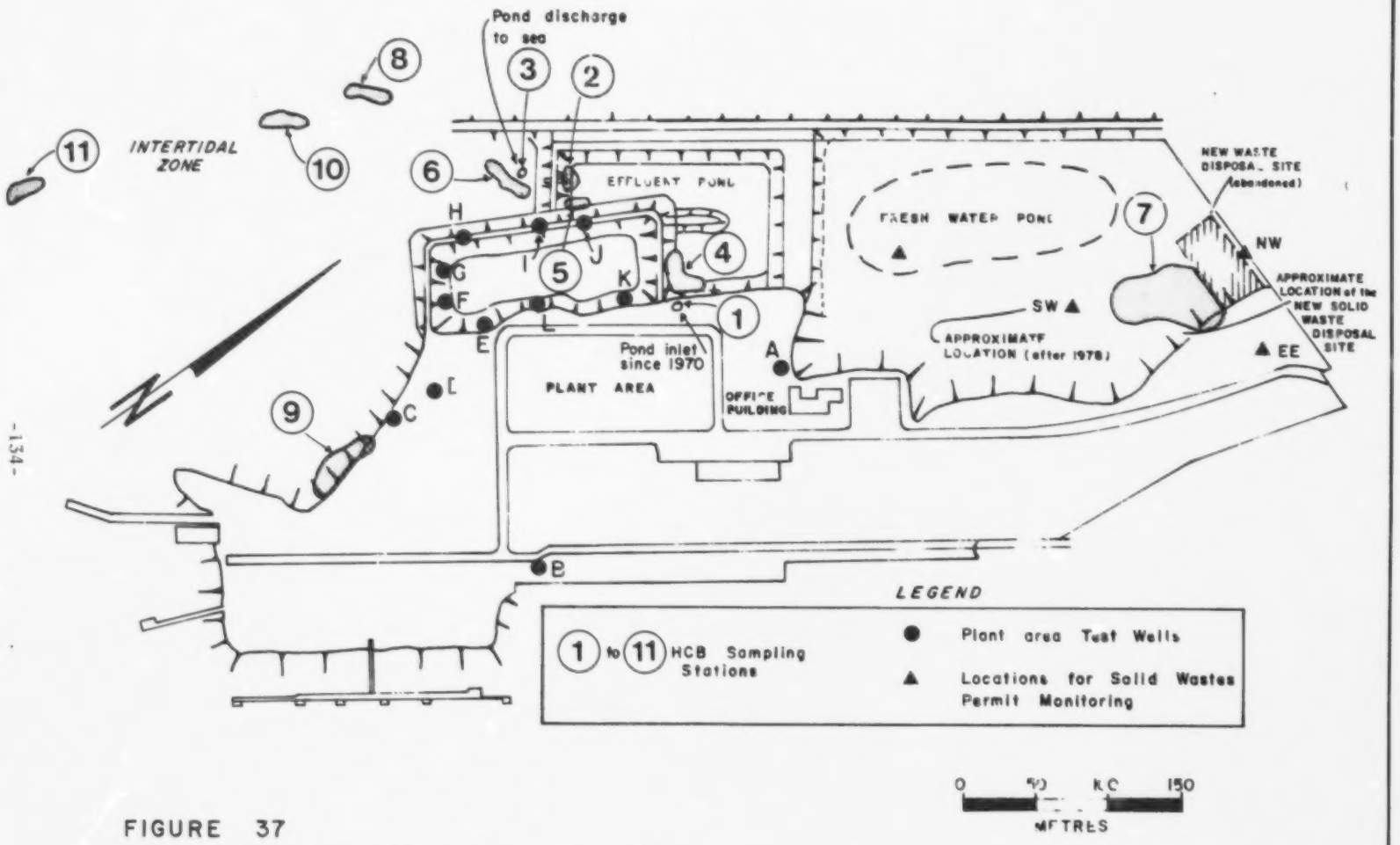


FIGURE 37

HCB SAMPLING STATIONS AT FMC

(From Dept. of the Environment, EPS. Unpublished.)

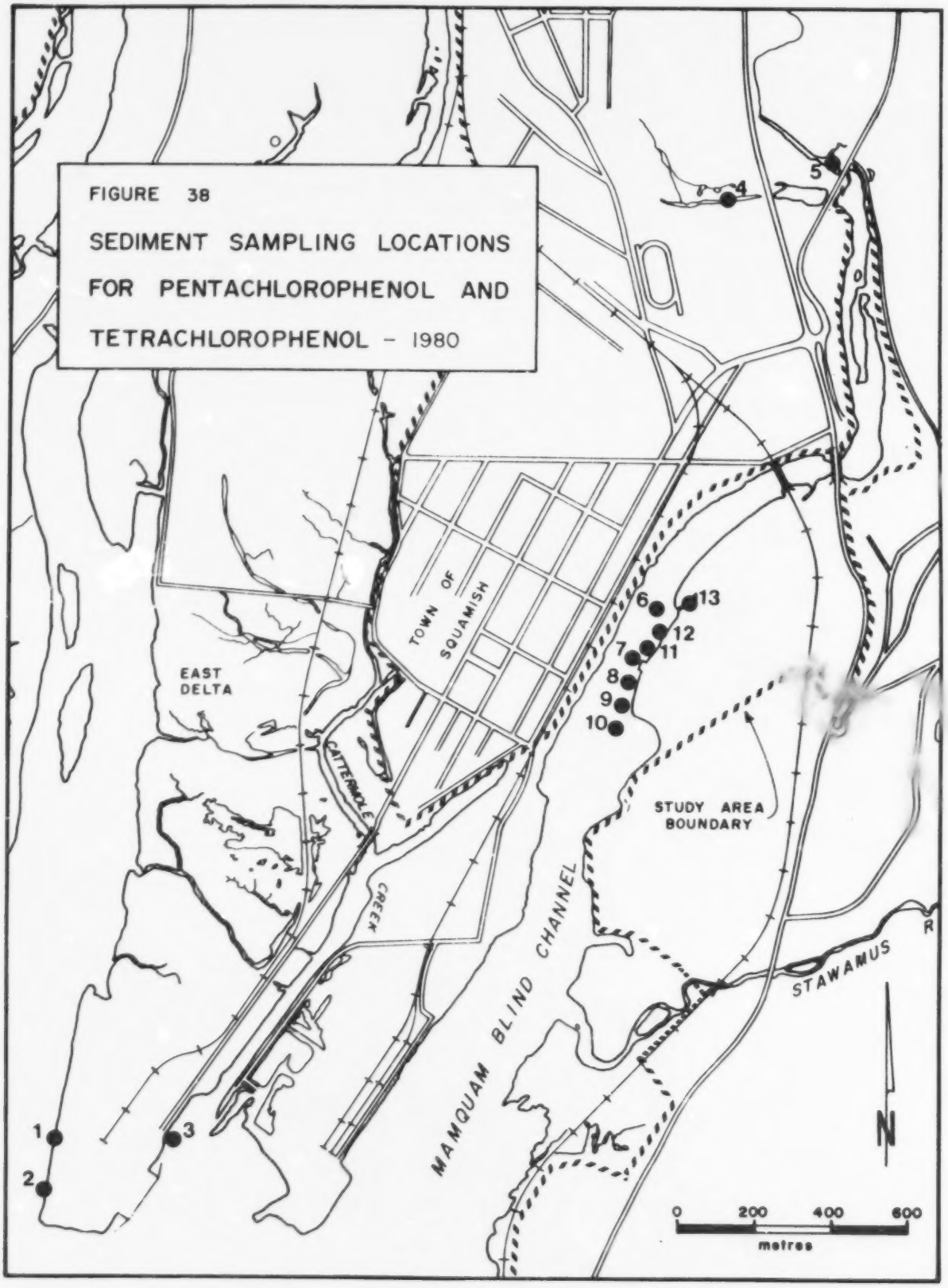


FIGURE 38
SEDIMENT SAMPLING LOCATIONS FOR PENTACHLOROPHENOL AND TETRACHLOROPHENOL - 1980
TOWN OF SQUAMISH
EAST DELTA
CATTERMOLE CREEK
MAMQUAM BLIND CHANNEL
STUDY AREA BOUNDARY
STAWAMUS R
1
2
3
4
5
6
7
8
9
10
11
12
13
N
0 200 400 600
metres

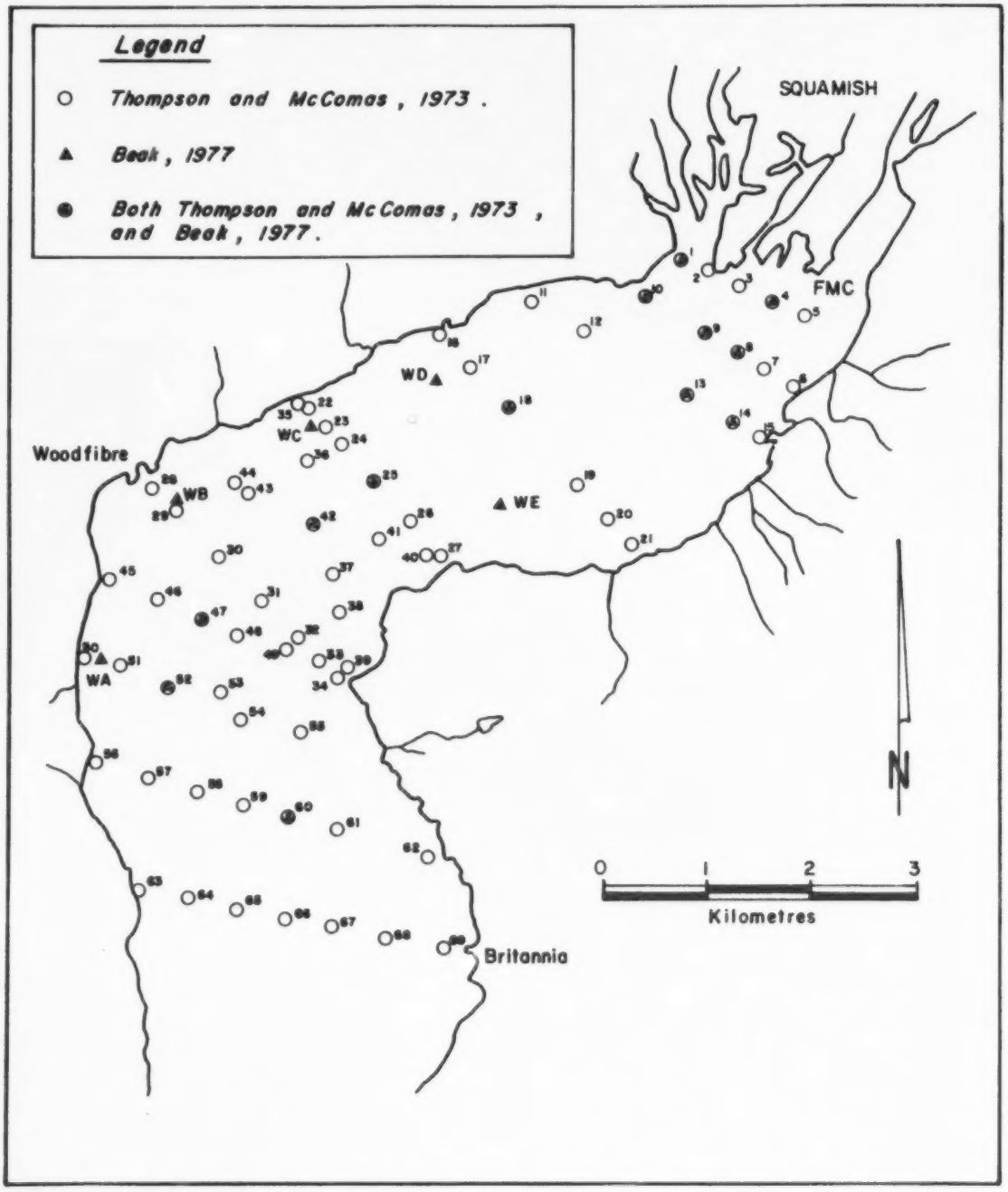


FIGURE 39. TRANSECT STATIONS FOR PHASE ONE AND TWO OF SEDIMENT SAMPLING PROGRAM

(From BEAK, 1978)

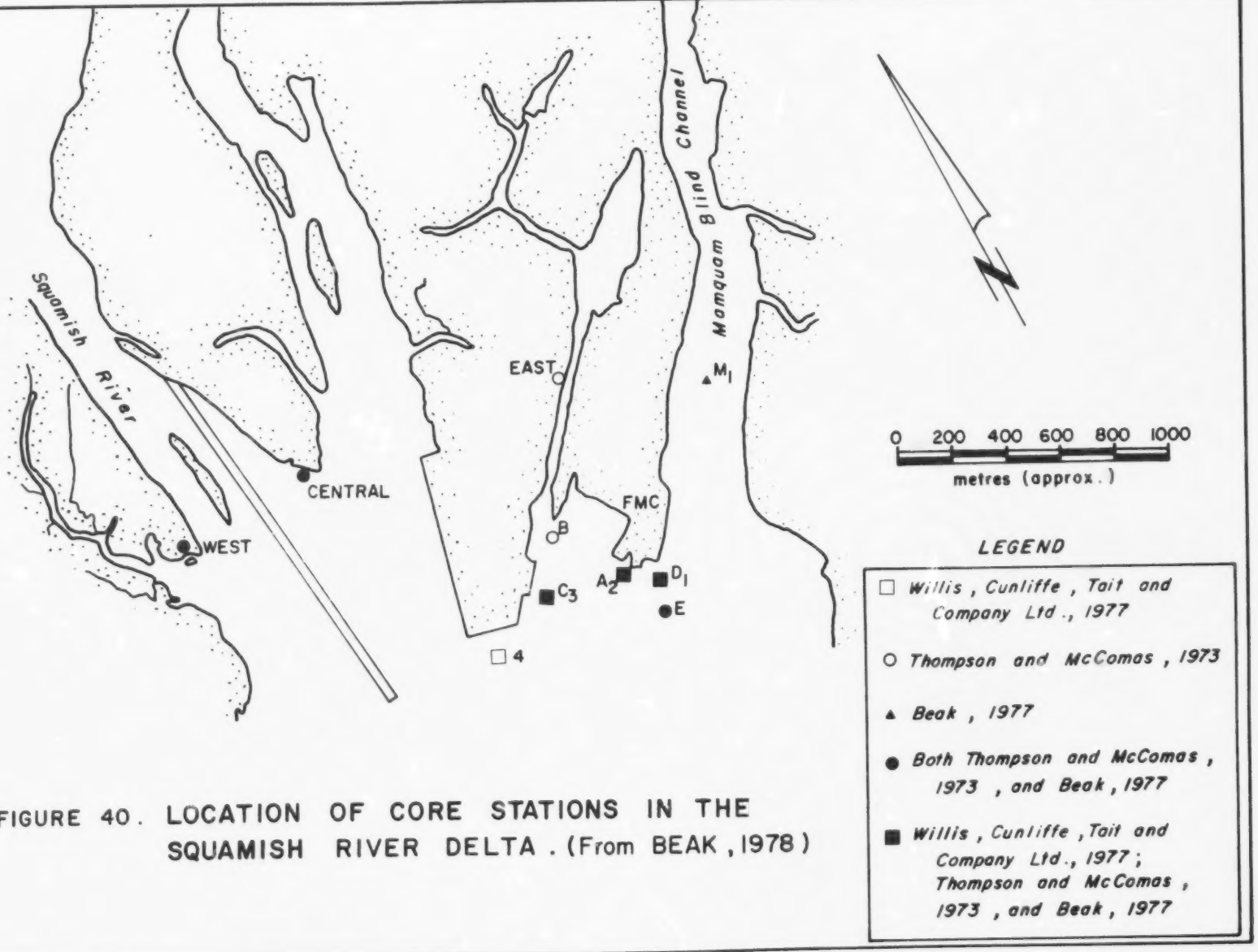
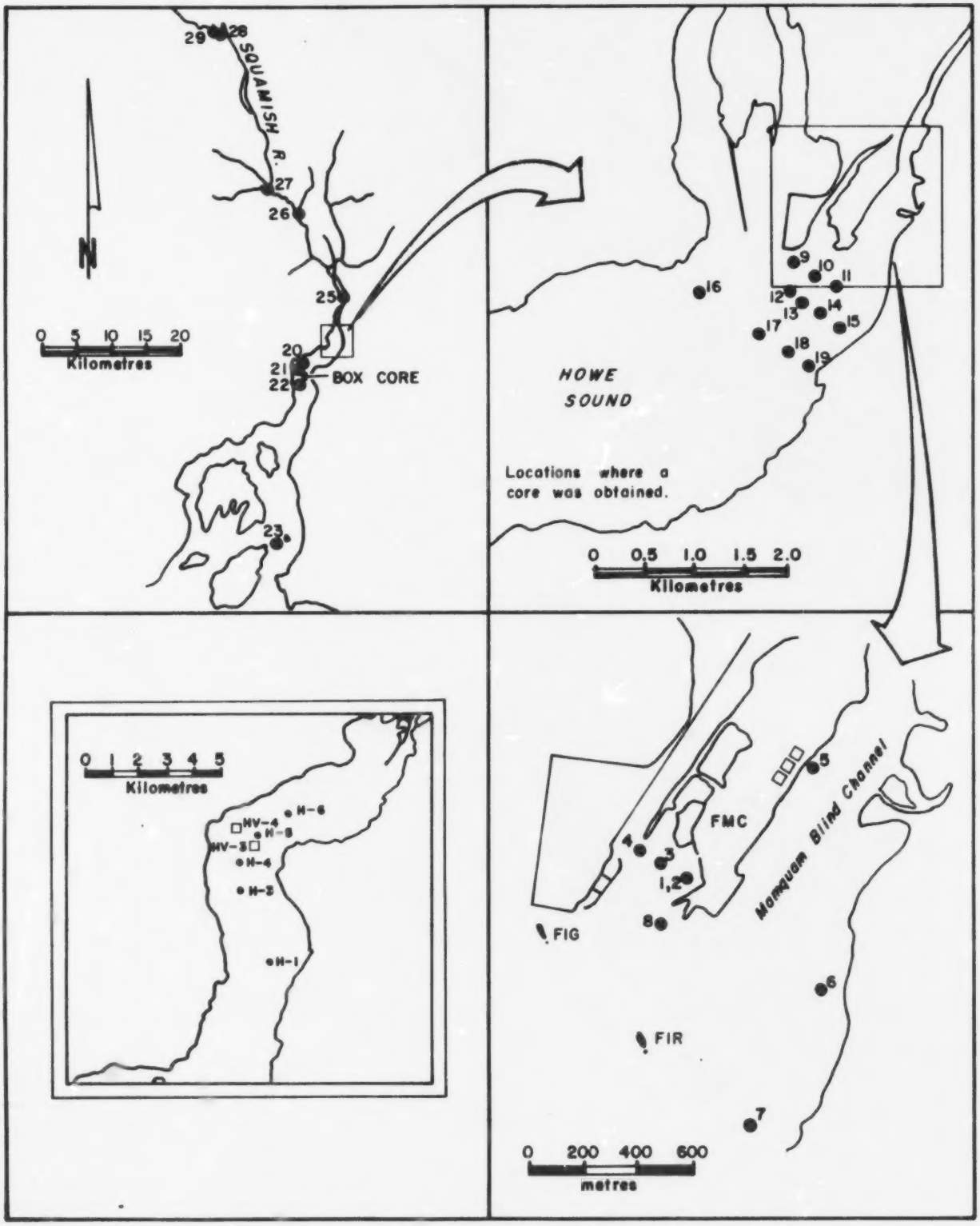


FIGURE 40. LOCATION OF CORE STATIONS IN THE SQUAMISH RIVER DELTA. (From BEAK, 1978)

FIGURE 41. LOCATIONS WHERE GRAB SAMPLES WERE OBTAINED (FROM Macdonald and Wong , 1973)



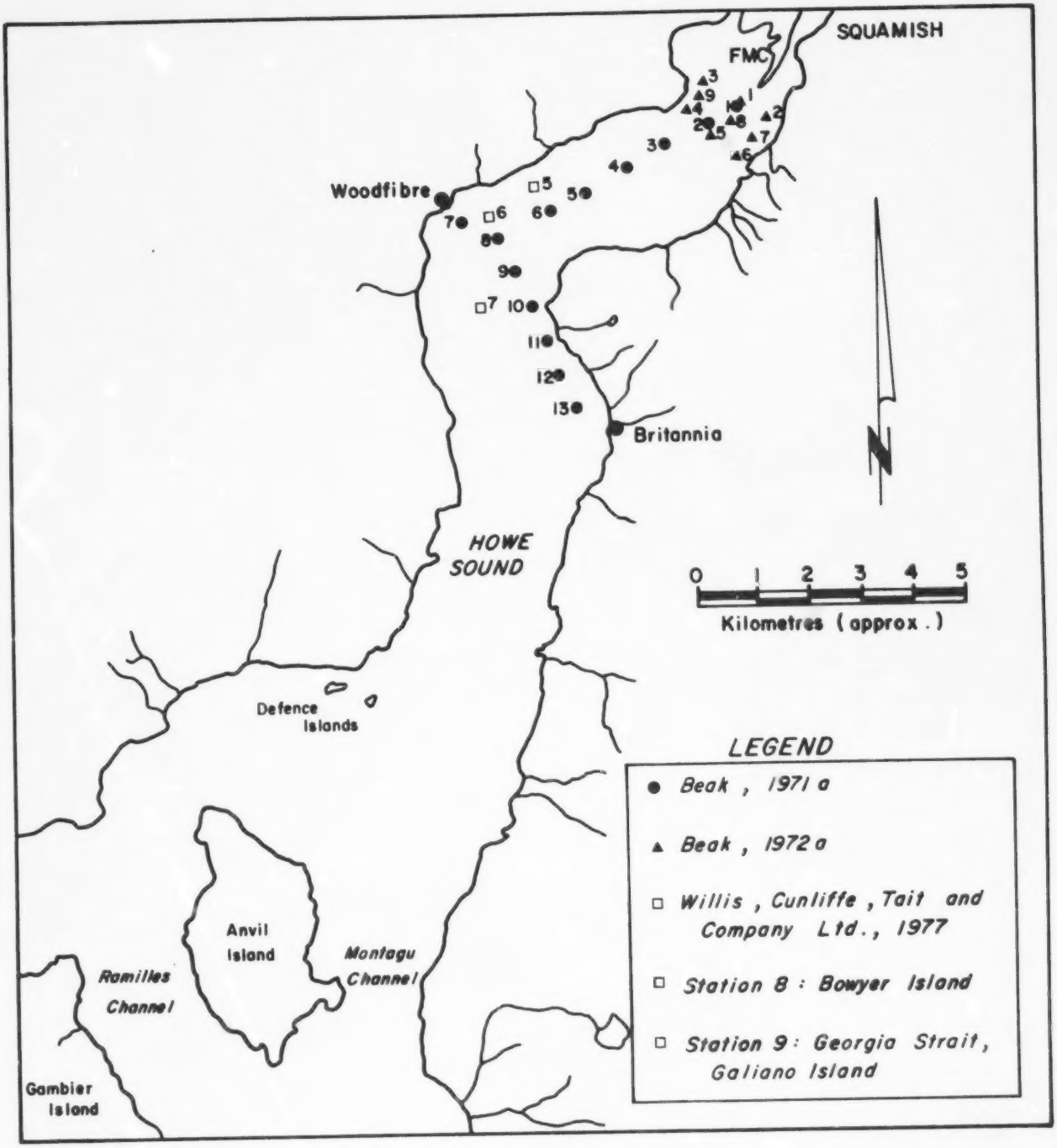


FIGURE 42. LOCATION OF SEDIMENT SAMPLING POSITIONS
(From BEAK, 1978)

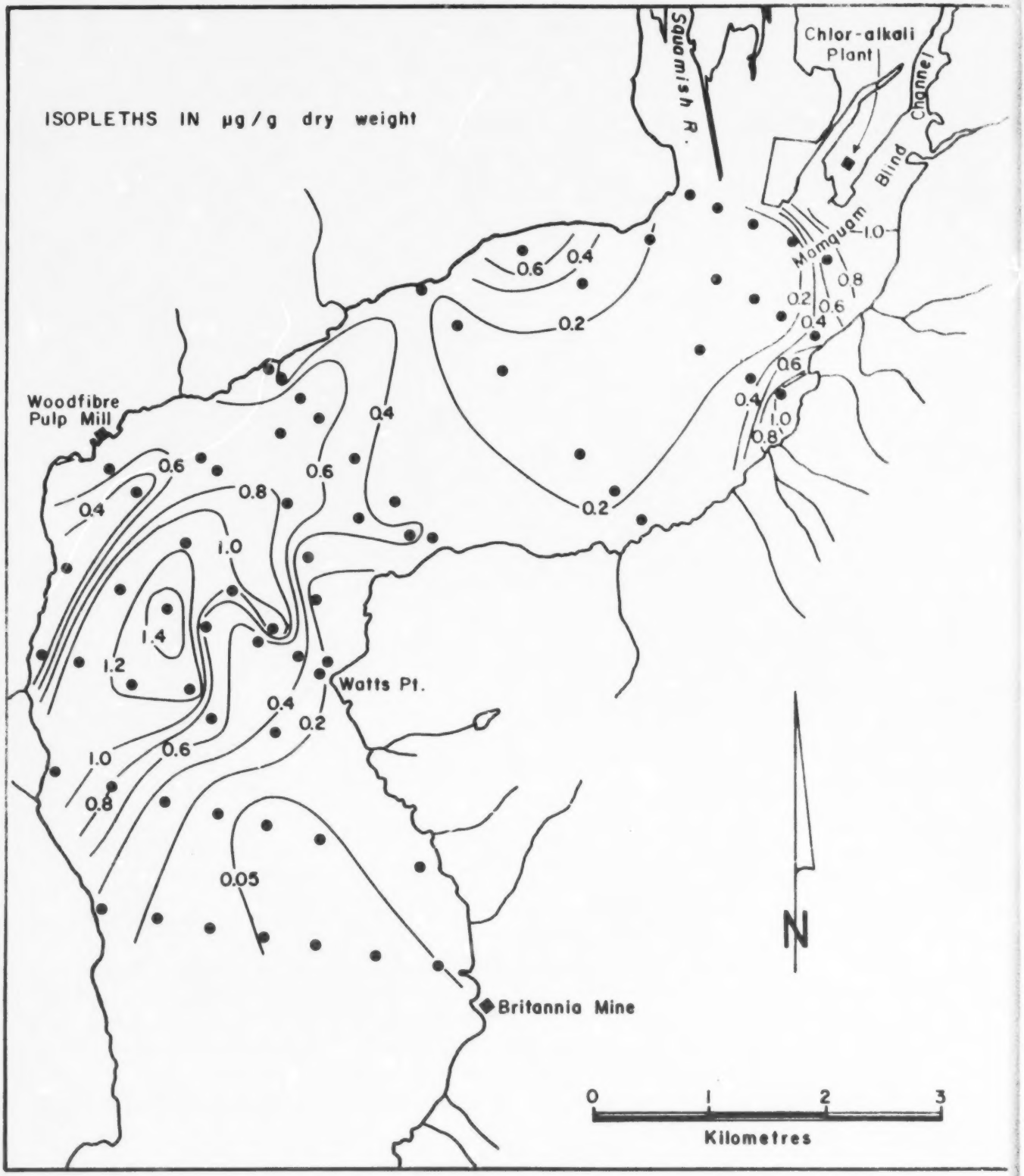


FIGURE 43 . **MERCURY ISOPLETHS FROM GRAB SAMPLES (1972)**
(Thompson , Macdonald and Wong , 1980)

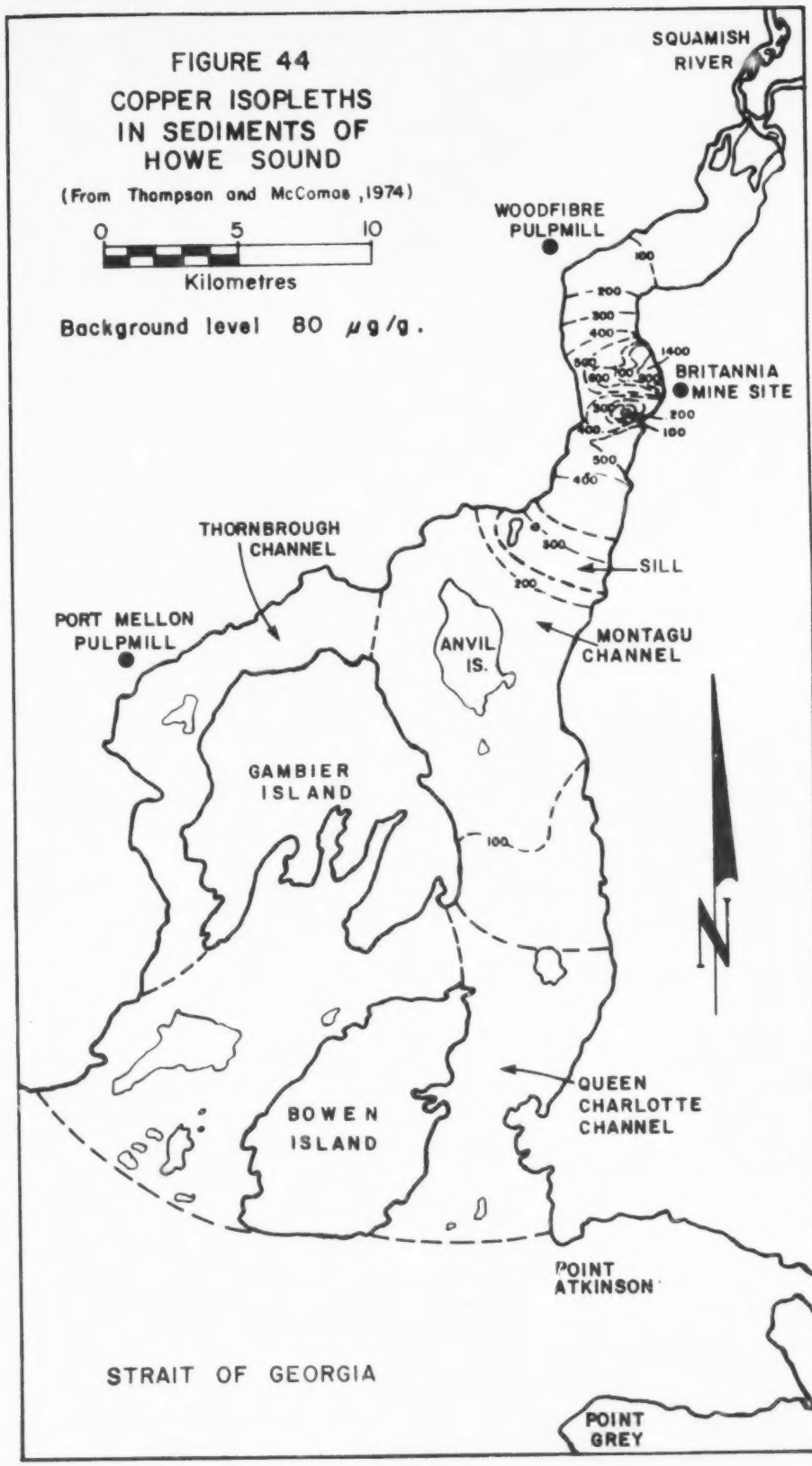


FIGURE 44
COPPER ISOPLETHS
IN SEDIMENTS OF
HOWE SOUND
(From Thompson and McComas, 1974)
0 5 10
Kilometres
Background level 80 µg/g.
SQUAMISH RIVER
WOODFIBRE PULPMILL
BRITANNIA MINE SITE
THORNBROUGH CHANNEL
PORT MELLON PULPMILL
SILL
MONTAGU CHANNEL
ANVIL IS.
GAMBIER ISLAND
BOWEN ISLAND
QUEEN CHARLOTTE CHANNEL
POINT ATKINSON
STRAIT OF GEORGIA
POINT GREY
N

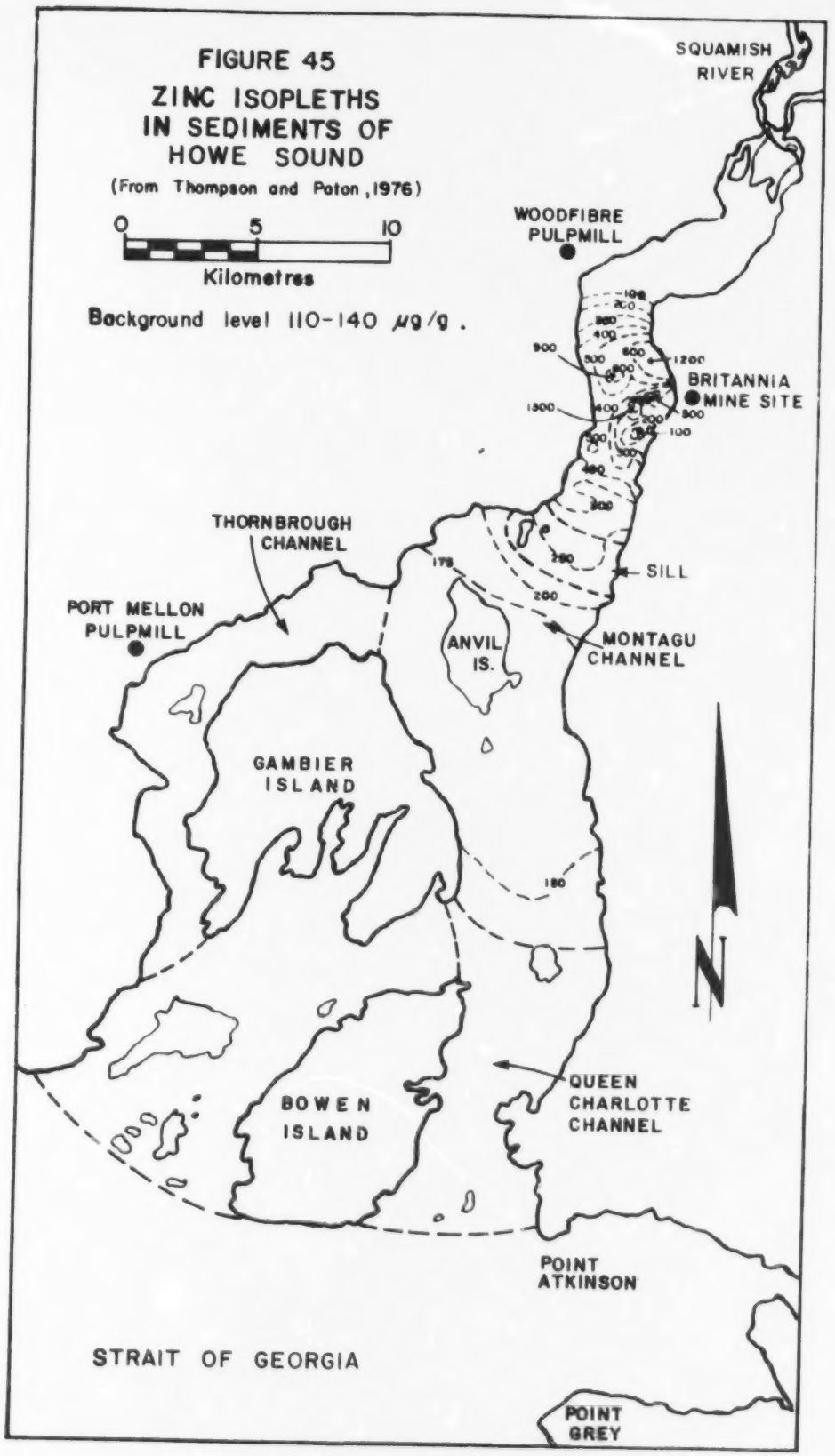


FIGURE 45
ZINC ISOPLETHS
IN SEDIMENTS OF
HOWE SOUND
(From Thompson and Paton, 1976)
0
5
10
Kilometres
Background level 110-140 µg/g.
SQUAMISH
RIVER
WOODFIBRE
PULPMILL
BRITANNIA
MINE SITE
THORNBROUGH
CHANNEL
PORT MELLON
PULPMILL
SILL
ANVIL
IS.
MONTAGU
CHANNEL
GAMBIER
ISLAND
N
BOWEN
ISLAND
QUEEN
CHARLOTTE
CHANNEL
POINT
ATKINSON
STRAIT OF GEORGIA
POINT
GREY

FIGURE 46

BALLOON POSITIONS AT 09:00 PST NOVEMBER 26, 1980

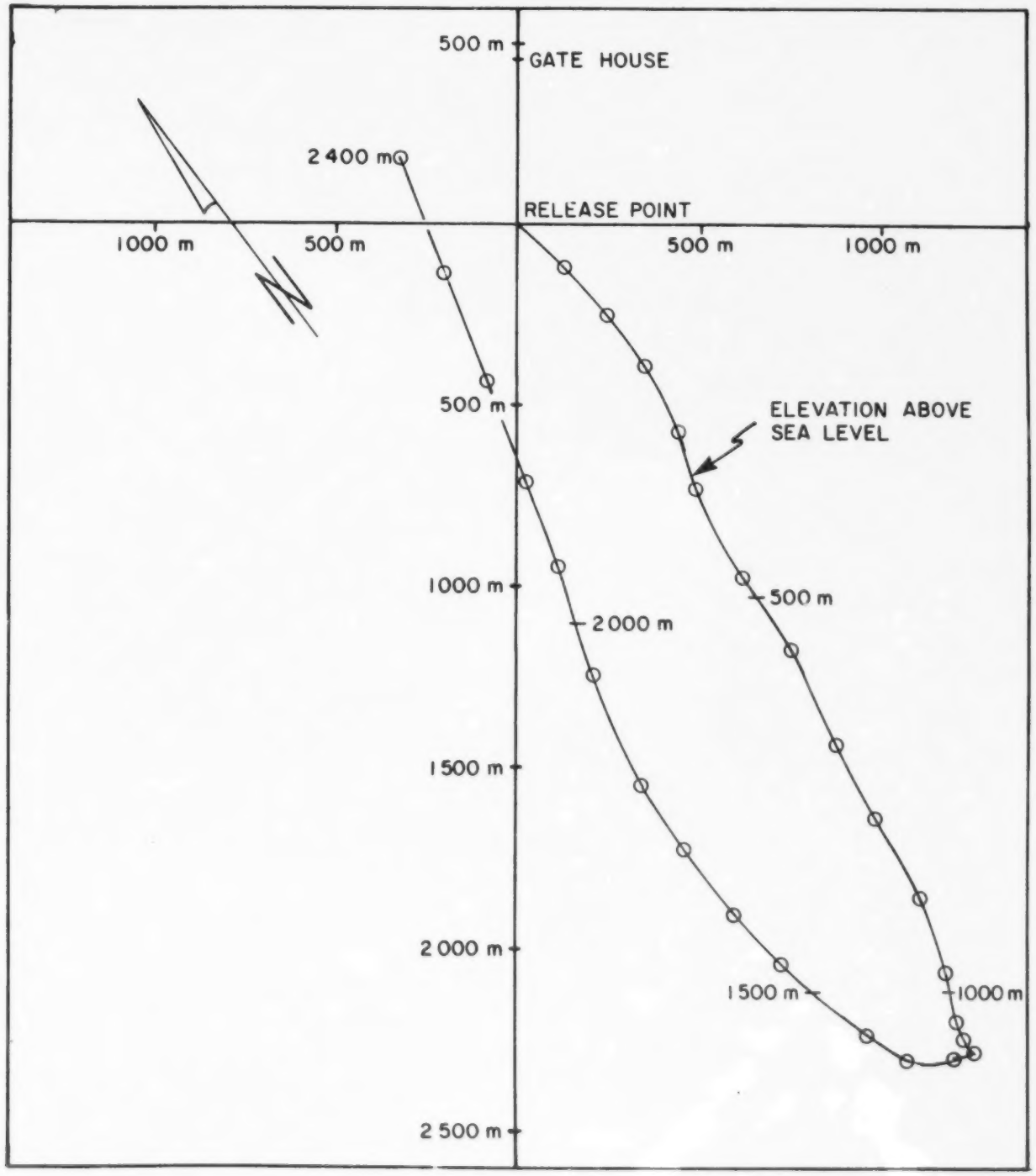
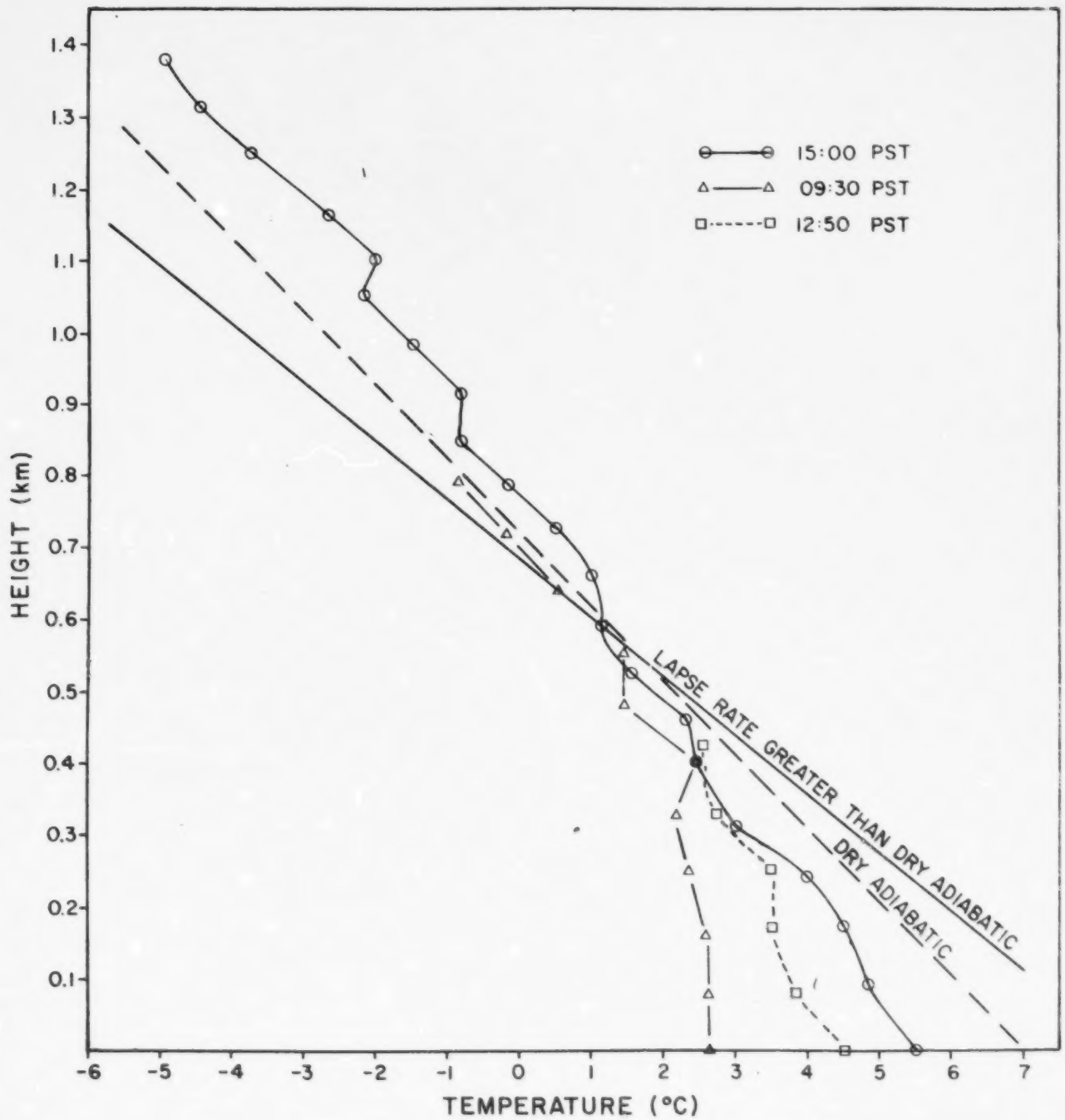


FIGURE 47

TEMPERATURE VERSUS HEIGHT AT SQUAMISH
NOVEMBER 25, 1980



Tables

TABLE 1

EXISTING WATER LICENCES AND WATER USERS IN THE SQUAMISH AREA

Licence Number	Watercourse	Holder	Licensed Quantity	Purpose	Comments
36347	Stawamus (to Mamquam Channel)	District of Squamish	11 365 m^3/d	Waterworks	Main water supply for Squamish & Brackendale
Approval 43	Stawamus		Entire Flow	River Channelization	Flood Control
25775	Mashiter Creek/ Estate Springs	District of Squamish	680 m^3/d	Waterworks	Mashiter Creek drains into Mamquam R. This water is not currently used.
27696	Meigham Creek	District of Squamish	45 m^3/d	Industrial	Meigham Creek drains into Mamquam Creek
35041	Mamquam R.	Squamish Valley Golf Club	154 185 m^3/yr	Irrigation	(Season estimated May-September inclusive)
37960	McLain Brook		19 735 m^3/yr	Irrigation	"
3174	Hop Ranch Creek	Stevenson Holdings	30 837 m^3/yr	Irrigation	Hop Ranch Creek Flows to Squamish River
20093	Dryden Creek		5 m^3/d	Domestic	Dryden Creek & Norman Creek in Brackendale area, drains to Squamish River
52897	Norman Creek	H.E. Barr	18 m^3/d	Land Improvement	See Above
	Other Water Users	Weldwood Canada	390 m^3/d	Cooling Water	Discharge to Mamquam Channel Source: Squamish Waterworks
		F.M.C.	33 000 m^3/d	Cooling Water	Saline tidal channel source Discharge to tidal channel
		CanadianOxy (Hooker) Chemicals	6 800 m^3/d	Cooling Water	Saline tidal channel source Discharge to tidal channel terminated 1980

TABLE 2

POLLUTION CONTROL PERMIT CONDITIONS

WELDWOOD OF CANADA LTD. EMPIRE LUMBER MILL

AIR EMISSIONS (PA 2601)

Emission Source	Type of Emission	Permitted Rate (SCFM)	Emission Characteristics and Monitoring Requirements
Planermill Chip Cyclone	wood particulate	7 750	Particulate matter 0.001 Grains/SCF (based upon 24 hour continuous operation) - Determine and record concentration of particulate matter and average daily emission rate - To be sampled once every six months over a period representative of Mill operation
Sawmill Sawdust Cyclone	"	2 590	
Sawmill Chip Cyclone	"	19 350	
Planermill Chip Cyclone	"	2 800	
Sawmill Fines Cyclone	"	2 800	
Sawmill Shavings Cyclone	"	51 000	
Sawmill Chip Bin	"	7 750	To be monitored by Waste Management Branch and to be amended after one year of observation
Sawmill and Planermill Air Valves and Cylinders	unspecified	2 400	

LIQUID EFFLUENT (PE 4951)

	Objective	Maximum Permitted Value	Required Monitoring Frequency	Period of Record	Number of Values	Value
Temperature (^{o}C)	35	35	Monthly	1979	1	15
pH (range)	6.5-8.0	-	-	1979	1	6.6
Suspended Solids	60	-	-	1979	1	<1
Specific Conductance	-	-	-	1979	1	59
BOD_5	50	-	-	1979	1	10
Flow (m^3/d)	-	390	Weekly	1979	1	-

- No value or requirement

SOLID WASTE (PR 4879)

Characteristics	Permit Requirements
Wood bark, scrap, ans gravel	Cover with earth to depth of 0.6 m Operate as class "B" landfill Install Monitoring Wells

TABLE 3

POLLUTION CONTROL PERMIT CONDITIONS

WOODFIBRE

Stack	Parameters	Permitted Value	No. of Values in Indicated Range	1979 Values				1980
				Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.	Jan.-Mar.
Recovery Boiler (total for 3 stacks)	Particulate (kg/ADU_t)	5 avg. 10 max.	-	14.1	15.3	21.4	-	-
	Bivalent Sulphur (H_2S)	20 ppm_v avg. 70 ppm_v max.	<20	1	0	0	3	3
			20< x < 70	2	4	5	37	14
			>70	1	7	5	4	6
Fuel Oil Fired Power Boiler Stack	Particulate (mg/mol @12% CO_2)	3.6 avg. 5.5 max.	-	-	-	-	1.4	-
	Volume (mol/s)	1180	-	-	-	-	1180	-
	Sulphur Dioxide (ppm_v)	600	-	400	400	400	400	400
Wood Waste Fired Power Boiler Stack	Particulate (mg/mol 12% CO_2)	16.6 avg. 24.9 max.	-	45.5	-	19.5	44.8	47.8
	Volume (mol/S)	2160	-	1208	-	1256	1888	1963
Lime Kiln and Dissolving Tanks	Particulate* (kg/ADU_t)	1 avg. 1.5 max.	-	0.34	-	0.51	0.51	0.65
	Bivalent Sulphur (S) Kg/ADU_t	0.7 avg. 1.5 max.	-	-	0.002(a) 0.005(b) 0.30 (c) 0.005(d)	-	-	-

* Total for 4 stacks

ADU_t - air dried unbleached tonne of pulp produced

ppm_v - ppm on a volumetric basis

a "A" LIME KILN STACK
b DISSOLVING TANK "A"
c WEAK BLACK LIQUOR OXIDATION TOWER
d BROWN STOCK WASHER HOOD "A"

TABLE 4

POLLUTION CONTROL PERMIT CONDITIONS

REICHHOLD LTD.

BARK CONVERSION PLANT

(PA 5765)

Emission Source	Permitted Volume (mol/s)	Permitted Value Particulate Matter (mg/mol)
Bark Drier Cyclone	280	2.8
Bark Grinder Bag Filters	210	2.8
Monitoring Requirements	Visual monitoring of the discharges will be carried out by the Waste Management Branch after start up. Based on these results the Regional Manager may require source monitoring by the permittee. The results of such monitoring to be summarized and submitted as required.	

TABLE 5

FMC OF CANADA LTD.

SQUAMISH

AIR EMISSIONS DATA SUMMARY

		Permitted Value	1979				1980
			Jan-Mar	Apr-Jun	July-Sept	Oct-Dec	Jan-Mar
West HCl Plant Stack	Flow rate (mol/s)	1.86 avg. 3.43 max.	1.06	1.17	0.66 0.71	1.23	0.79
	HCl (μg/mol)	1.83	1.12 0.70	0.24	0.22 0.54	0.37 0.27	0.07 0.10
East HCl Plant Stack	Flow rate (mol/s)	1.86 avg 3.43 max	1.12	1.5	0.79 0.78	0.5	0.71
	HCl (μg/mol)	1.83	0.81	0.03 0.07	0.49 0.12	0.03	0.03 0.04
Cell Vent Stack	Flow rate (mol/s)	22.6	-	-	18	16.3	15.8
	Mercury Emission Rate (g/tonne chlorine)	0.1	-	-	0.0017	0.0001	0.0004
Hydrogen Vent Stack	Flow rate (mol/s)	28	25.7	25.9	23.8	17.1	21.4
	Mercury Emission Rate (g/tonne chlorine)	0.1	0.0012	0.0048	0.0131	0.0001	0.0243
Cell Room Areas*	Mercury ($\mu g/m^3$)	50 max	-	20.6 avg 4.4-69.9	21 avg 4.7-55.6	14.4 avg 3.4-32.6	13.3 avg 1.5-34
Ambient Air - Plant Boundary - Pemberton Street	Mercury ($\mu g/m^3$)	1 max	0.13 0.03	0.53 0.18	0.52 0.07	0.05 0.02	0.06 0.03

* Results from six areas

TABLE 5 (CONTINUED)

CAUSTIC SCRUBBER STACK

Chlorine Emissions

Permitted Value	No. of Values in Indicated Range	1979						1980		
		July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
0.1 ppm_v avg.	<0.1	4	8	8	21	16	24	0	0	4
0.3 ppm_v max.	0.1 < x < 0.3	4	14	6	7	14	2	14	21	22
	>0.3	3	5	3	0	0	0	11	4	2
Maximum Instantaneous Recorded Value		5	8	8						

MERCURY IN DUSTFALL
1980

	Soluble	Insoluble
Station #1		
August 20 - September 25	<0.007	>0.028
September 25 - October 23	<0.007	>0.039
Station #2		
August 20 - September 25	<0.007	0.028
September 25 - October 23	<0.007	0.035

TABLE 6

SUMMARY OF MONITORING DATA FOR F.M.C.

	Cooling Water+ 0301036			Filtrate from Slude Drying 0301024			Influent to Settling Lagoon 0301025			Effluent PE 138			Max Permit Level
	VALUES												
	No.	mean	range	No.	mean	range	No.	mean	range	No.	mean	range	
Chlorine-residual mg/L							1	< 0.1		2432	0.022*	0-4.7	0.15
Flow m /d				182	58.1*	0-259.2				2111	27422*	0-43761	
Hydrogen Peroxide mg/L										2412	0.12*	0-2.96	1
Mercury µg/L	79	0.41*	< 0.05-5.5	2529	21.4*	6 -40	8	20	0.88-68	2521	3 *	0.1-75	8
pH	4	7.5	6.7 -7.9	2443	12*	2 -12.9	1955	7.4*	3.1 -11.1	2540	7.6*	3.1-9.9	6-9
Sulphide-total mg/L				2524	0.53*	0 -8.8	4	< 0.5		2438	< 0.09*	0-.1	0.5
Suspended Solids mg/L	185	106	0-3220				6	6	3-9	2519	1.98*	< 0 -31.9	10
Calcium mg/L	3	328	272-437				3	296	273-325	6	296	270-325	
Copper-total mg/L							1	0.003		6	0.025	0.004-0.05	
Hardness mg/L	3	4911	4092-6113				3	4795	4195-5668	6	4764	4070-5602	
Iron-total mg/L							1	0.179		6	0.35	< 0.1-0.68	
Lead-total mg/L							1	< 0.001		6	0.001	< 0.001-0.003	
Magnesium-dis mg/L							3	986	844-1180	6	978	825-1170	
Oxygen - dis mg/L										16	10.2	8.4-11.8	
Sulphate mg/L	3	1978	1820-2100				3	1994	1890-2100	5	1963	1770-2132	
Solids - dis mg/L	3	29333	26900-31100				3	28567	25600-31100	9	27560	21500-30600	
Zinc - total mg/L										5	0.035	< 0.005-0.08	

+Originates as seawater

*Required Monitoring

TABLE 7

MERCURY IN SLUDGE

DATA SUMMARY

FMC CANADA

Year	Monthly Loadings (kg)			Total Yearly Loading (kg)
	Maximum	Median	Minimum	
1973	6.65	2.12	1.38	29.4
1974	16.53	2.54	0.86	48.7
1975	4.46	0.73	0	14.7
1976	17.57	2.3	0.85	43.6
1977	7.08	1.9	0.25	26.7
1978	12.8	6.3	2.54	84.5
1979	9.4	5.6	2	68.9
1980*	8.38	6.2	0	34.8

*January to July Period

TABLE 8

FMC TEST WELL MONITORING DATA SUMMARY

Test Well/Sample Location	Period of Record	No of Values	Mercury Concentration (µg/L)		
			Maximum	Median	Minimum
Solid Waste					
East (EE)	1975-1978	41	13.7	1	< 0.1
NW	1975-1978	41	7 9	1.1	< 0.1
SW	1975-1978	41	5.2	0.7	0.1
Abandoned Settling Pond					
A	1971	2	6.2	4.5	2.9
A	1978	17	3.7	1.6	0.7
B	1978	16	3.8	1.2	0.3
C	1978	16	2.7	0.8	0.2
D	1971	1	36	-	-
D	1978	16	0.8	0.4	< 0.1
E	1971	1	135	-	-
E	1978	20	34	14	3
F	1971	2	28	24.5	21
F	1978	20	7960	2810	600
G	1971	2	9.7	7.4	5.1
G	1978	20	1050	715	320
H	1971	2	4.3	4.3	4.3
H	1978	20	1690	1005	240
I	1978	16	180	86	43
J	1978	16	41	19	3.6
K	1978	16	1470	760	140
L	1978	16	14400	8450	3400

TABLE 9

HOOKER CHEMICALS

MONITORING DATA SUMMARY

Air Emissions

		Permitted Value	Period of Record	No. of Values	Values		
					Max	Mean	Min
Caustic Scrubber	Chlorine (ppm_v)	10 max	1978 1979	25 26	8 9	4.96 4.34	1 1
	Total Particulates (mg/mol)	-	1974 1975 1976	4 4 4	0 0 0	0 0 0	0 0 0

Brine Sludge

Parameter	Permitted Value(s)	Period of Record	No. of Values	Values		
				Max	Mean	Min
Copper-total (mg/L)	-	1973-1975	4	0.18	0.086	0.005
Flow(m^3/discharge)	*	1977-1979	47	27.2	9.4	0.9
Iron - total (mg/L)	-	1973-1975	4	120	30.8	0.6
Lead - total (mg/L)	-	1973-1975	4	0.014	0.004	<0.001
pH	5 - 10	1973-1979	54	10	8.2	5
Solids - total		1975	2	5536	3231	926
(mg/L) - suspended	-	1975	2	7	4.5	2
Zinc - total (mg/L)	-	1973-1975	4	0.27	0.15	0.06

* 0.9 m^3/day

\- No valve

Cooling Water

Parameter	Permitted Value	Period of Record	No. of Values	Values		
				Max	Mean	Min
Chlorine Residual (mg/L)	-	1973-1975	248	<0.1	0	0
Flow (m^3/d)	6820	1974-1975	524	5000	2221	0
pH	-	1973-1977	41	7.7	6.9	6.6
Solids - total	-	1974-1977	6	30600	4673	2790
(mg/L) - suspended	-	1974-1977	6	82	12.5	4
Temperature (°C)	-	1973-1977	481	57	32	27

\- No value

TABLE 9

(CONTINUED)

Chromium in ditch waters adjacent to landfill site†

Date	Total Chromium (mg/L)	
	Ditch Upstream	Ditch Downstream
October, 1979	0.008	0.06
June, 1980	-	0.02
October, 1980	<0.01	0.02

† Sampled by Waste Management Branch, Surrey.

TABLE 10

EFFLUENT MONITORING DATA SUMMARY

SQUAMISH TERMINALS

PE 1749

Parameter	Permitted Value*	Period of Record	No. of Values	Values*		
				Max.	Mean	Min.
Flow	2.27	-	-	-	-	-
Carbon-Organic	-	1974	1	<1	-	-
Oil and Grease	70	1974-1980	13	576	153.1	13
pH	-	1974-1977	10	6.8	6.4	5.9
Solids - Total	-	1974-1975	3	686	307	132
- Dissolved	-	1975	1	236	-	-
- Suspended	-	1974-1977	5	204	95	51
Specific Conductance	-	1974-1977	9	798	288	80
Sulphate	-	1974	1	5.3	-	-
Surfactants	-	1974	2	1.96	1.11	0.27
Turbidity	-	1975	1	16	-	-

* All values are mg/L except (1) Flow in m^3/d.
(2) pH
(3) Specific Conductance in µmhos/cm.
(4) Turbidity in J.T.U.

- No value

TABLE 11

EFFLUENT DATA SUMMARY

SQUAMISH CENTRAL STP

PE 1533

Parameter	Permitted Value	Period of Record	No. of Values	Values*		
				Max.	Mean	Min.
BOD_5	30	1974-1980	46	135	22.3	<5
Flow†	4 600	-	-	-	-	-
Suspended Solids	40	1974-1980	46	390	40.6	3.2
Chlorine Residual	-	1974-1980	29	>3	0.9	0.15
Coliform - Total	-	1974-1975	19	310 000	330**	2
- Fecal	-	1974-1980	32	5 400	13**	2
Nitrate-Nitrite	-	1975-1979	6	7.4	2.81	0.46
Kjeldahl Nitrogen	-	1975-1979	6	49	16	3
Ammonia	-	1977-1979	5	18.1	7.2	1.46
Total Phosphorus	-	1977-1979	4	7.6	4.36	2.1
pH	-	1974-1980	47	7.6	7.0	5.7
Cadmium - Total	-	1974	1	0.0005	-	-
Chromium - Diss.	-	1974	1	0.005	-	-
Lead - Total	-	1974	1	0.005	-	-
Manganese - Total	-	1974	1	0.05	-	-
Zinc - Total	-	1974	1	0.08	-	-

* Values are expressed as mg/L except:

(1) Flow which is as m^3/d
(2) Coliform which are as MPN/100 mL
(3) pH

** Geometric Mean

† Flows approximately 20-30 m^3/d less than recorded for the Mamquam STP (Table 12)-1980. Flow data not available due to problems with flow meter (R. Mihalick, personal communication).

TABLE 12

EFFLUENT DATA SUMMARY

MAMQUAM STP

PE 1512

Parameter	Permitted Value	Period of Record	No. of Values	Values*		
				Max.	Mean	Min.
BOD_5	30	1973-1980	59	>214	64	2
Flow†	4 540	1980	366	6 314	1 940	1 232
Suspended Solids	40	1973-1980	56	1 060	129	2
Chlorine Residual	-	1973-1980	27	2.4	0.74	0
Coliform-Fecal (1)	-	1974-1980	33	1 100 000	15 796**	23
-Fecal (2)	-	1974-1979	28	5 400	6**	2
-Total	-	1974-1975	19	1 400 000	677**	2
Nitrate-Nitrite	-	1975-1980	17	6.2	0.94	0.04
Ammonia	-	1973-1980	18	28.2	20.2	2.4
Kjeldahl Nitrogen	-	1975-1980	18	54	28.2	6
Total Phosphorus	-	1973-1980	18	16.9	5.9	2.9
pH	-	1973-1980	59	7.8	7.3	6.1
Cadmium-Total	-	1974-1980	6	0.002	0.0013	<0.0005
Chromium-Total	-	1974-1980	6	0.065	0.026	<0.005
Copper-Total	-	1974-1980	6	0.14	0.059	0.001
Iron-Total	-	1974	1	0.4	-	-
Lead-Total	-	1974-1980	6	0.04	0.015	0 005
Manganese-Total	-	1974	1	0.07	-	-
Zinc-Total	-	1974-1980	6	0.53	0.28	0.12

* Values as mg/l except (1) Flow which are as m^3/d
(2) Coliform which are as MPN/100 mL
(3) pH

** Geometric Mean

(1) Waste Management Branch Results

(2) Consultants for District of Squamish

† Flow data do not reflect instantaneous peak flows since flow recorder cannot record flows greater than approximately 3.16 m^3/min (R. Mihalick, personal communication).

TABLE 13

ESTIMATED CONCENTRATIONS OF UNDISSOCIATED AMMONIA*

pH	Temp. °C	Percent Un-Ionized Ammonia	Undissociated Ammonia Total Ammonia Concentration - mg/L				
			24	25	26	27	28
7.0	0	0.09	0.022	0.023	0.023	0.024	0.025
	10	0.19	0.046	0.048	0.049	0.051	0.053
	20	0.39	0.094	0.098	0.101	0.105	0.109
7.5	0	0.28	0.067	0.070	0.073	0.076	0.078
	10	0.58	0.139	0.145	0.150	0.157	0.162
	20	1.22	0.293	0.305	0.317	0.329	0.342
8.0	0	0.87	0.209	0.218	0.226	0.235	0.244
	10	1.82	0.437	0.455	0.473	0.491	0.510
	20	3.77	0.905	0.943	0.980	1.018	1.056
8.5	0	2.71	0.650	0.678	0.705	0.732	0.759
	10	5.55	1.332	1.388	1.443	1.500	1.554
	20	11.02	2.645	2.755	2.865	2.975	3.086
9.0	0	8.10	1.944	2.025	2.106	2.187	2.268
	10	15.67	3.761	3.918	4.074	4.231	4.388
	20	28.10	6.744	7.025	7.306	7.587	7.868

* Assuming 0 ppt salinity

TABLE 14

SUMMARY OF MISCELLANEOUS DISCHARGES ENTERING MAMQUAM CHANNEL

Site	Site Description	Date Sampled	Acidity pH 8.0 mg/L	Total Organic Carbon mg/L	Fecal Coliform (MPN/100 mL)	Oil and Grease mg/L	pH	Phenols mg/L	Specific Conductance µs/cm	Tannin and Lignin mg/L	Remarks
S_1	Culvert draining slough south of wood waste area PR-04879	80/07/24	4.9	3			7.3	0.005	6 600	0.6	
S_2	Culvert draining motel grounds east bank 50 m north of highway bridge	80/06/26			1 700						
S_3	Creek draining woodwaste landfill, Weldwood property 50 m south of railway	80/07/24	16.8	10			6.9	0.002	708	3	Numerous sculpins in creek on tidal flats
S_4	20 cm concrete pipe west shore of Weldwood log sort office	80/06/25			3 500						Discharge cloudy coloured
S_5	Storm sewer 50 m south of Weldwood office west shore										No flow
S_6	15 cm drainage pipe west shore at Esso Tank Farm north of Government Wharf	80/06/25				1.7					Oily buildup noted in sediments at discharge point
S_7	Culvert draining eastern border of Weldwood mill yard	80/06/26		11	>24 000	6.2		0.012			Oily film on discharge
S_8	Culvert draining dryland log sort west shore north of Stawamus River	80/06/26	14.7				6.2	0.012	85	25	Culvert discharge very dark brown

TABLE 15

BULK CHEMICALS

Site	Imported			Exported		
	Substance	Quantity Tonnes/Year*	Via	Substance	Quantity Tonnes/Year*	Via
F.M.C.	Hg	4 (1977)	Truck	Cl_2	56 860	Rail/Barge
	H_2SO_4	486	Rail	NaOH	64 080	Truck/Barge
	Na_2S	6.5	Truck	HCl (32%)	9 935	Truck
	H_2O_2	16	Truck			
	H_3PO_4	5.4	Truck			
Hooker Chemical	NaOH	270	Truck	$NaClO_3$	12 245	Rail/Truck
	HCl	650	Truck			Truck
	$Na_2Cr_2O_7$	21.8	Truck			Truck
Squamish Terminal	Woodrite	<27 000 L/yr*	Truck			Truck
Weldwood	Woodrite	4 500 000 L/Yr*	Truck			Truck

(1) Source: Ministry of Environment, Waste Management Branch, Regional Office, Vancouver. Unpublished Data.

* Except where so noted, as litres/year (L/yr)

TABLE 16

HANDLING AND STORAGE OF CHEMICALS OF WOODFIBRE[1]

Chemical	Annual Consumption (Tonnes)*	Average Amount Per Shipment (Tonnes*)	Average Inventory	Transport Method
Chlorine	12 020	230	310	Barge/Rail Car
NaOH	14 060	270	360	Barge/Bulk
$NaClO_3$	4 080	115	225	Barge/Bulk
H_2SO_4	7 980	190	225	Barge/Rail
SO_2	1 135	45	90	Barge/Rail
$CaCl_2$	180	23	45	Truck
Na_2SO_4	4 535	180	270	Barge/Rail
Vanillin	6 350	135	135	Barge
Methanol	180	15	6.4	Truck
Muriatic Acid	5	1.4	0.3	Truck
Nitric Acid	18	1.5	-	Truck
Caustic Soda	11 450 L	-	795 L	Truck
Calfoam Defoamer			<45 In Total	Truck
Ipegal Surfactant				Truck
Alchem 19				Truck
Alchem 7215				Truck
Hiphilm #2 (Corrosion Inhibitor)				Truck
Alchem 623 (Polymer Flocculant)				Truck
Alechem 607 (Coagulant)				Truck

* Except where noted as Litres (L)

[1] Source: Ministry of the Environment, Waste Management Branch, Regional Office, Victoria. Unpublished data.

TABLE 17

SUMMARY OF ACCIDENTAL SPILLS: 1973 TO 1980[1]

Site	Year	Substance	Quantity	Comments
Woodfibre	1979	Bunker C	320 Litres	
Woodfibre	1979	Bunker C	160 Litres	
Unspecified	1979	Slick	Unspecified	3 Reported Incidents
Unspecified	1979	Garbage	Unspecified	Dumped From Ship
Chlor-Alkali Plant	1977	Chlorine	0.44 Tonne	
Unspecified	1977	Slick	Unspecified	
Unspecified	1976	Slick	Unspecified	2 Reported Incidents
Mamquam River	1976	Phoschek (Fire Retardant)	135 Litres	B.C. Forest Service
Unspecified	1975	Slick	Unspecified	2 Reported Incidents
Chlor-Alkali Plant	1975	Brine Containing Mercury in Solution	1.8 Kg Hg	
Woodfibre	1974	Bunker C	75 Tonnes	
Woodfibre	1974	Vanillin Liquor	2 726 Tonnes	
Unspecified	1974	Slick	Unspecified	
Mamquam Channel	1973	PCP	Unspecified	Empire Mills

Source: Department of Environment, Environmental Protection Service, Unpublished Data.

TABLE 18

PESTICIDE USE IN THE SQUAMISH AREA 1978/79

(1978)

Permit Number	Applicant/Location	Purpose	Area Sprayed (ha)	Chemical
105-46B	BC Hydro Brackendale	Brush R/W Control	4 ha	Brushkiller 64 2,4-D
105-46D	BC Hydro Garibaldi Area	Brush Control	40 ha	2,4-D 2, 4, 5-T
105-52	BC Hydro Green R.	Brush Control	40 ha	stump & 2,4-D & truck spray
105-64	BC Hydro Garibaldi	Brush Control	20 ha	2,4-D stump & truck spray
123-3	N. Vancouver to Berken	Conifer release	160 ha picloram	stump stomp & truck spray
123-5	N. Vancouver to Berken	Weed Control	115 ha	Hyvar & Tordon truck boom spray
123-7	N. Vancouver to Lilloett	Weed Control	628 ha	Hyvar & Tordon truck boom spray

TABLE 18 (CONTINUED)

PESTICIDE USE IN THE SQUAMISH AREA 1978/79

(1979)

Permit Number	Applicant/Location	Purpose	Area Sprayed (ha)	Chemical
105-33	BC Hydro Cheekeye Sub D.	Brush Control	40 ha	2,4-D backpack spray
105-14	BC Hydro Cheekeye	R/W Control	40 ha	2,4-D backpack
105-16	BC Hydro Cheekeye Sub STAT	Brush Control	64 ha	Tordon hand spray
105-17	BC Hydro Daisy Lake	Brush Control	12 ha	Tordon hand spray
105-18	BC Hydro Stawamus Pass	Brush Control	30 ha	Tordon Helicopter
105-20	BC Hydro Daisy Lake	Brush Control	49 ha	Tordon hand spray
105-21	BC Hydro Daisy Lake area	Brush Control	48 ha	2,4-D & Tordon backpack & hand spray
105-54	BC Hydro Squamish area	Brush Control	<128 ha	spike 80 W Tank spray

Source: 1978: Department of Fish and Wildlife. Summary of 1978 pesticide control act permit applications. Unpublished records.

1979: Department of Fisheries and Oceans. Pesticide control act files. Unpublished records.

TABLE 19

CHLOROPHENOXY RESIDUES IN FOREST SOIL/LITTER AT DIFFERENT TIME INTERVALS POST APPLICATION (SQUAMISH, B.C.)*

Time	Concentration - PPM	
	2,4-D	2,4,5-T
(Hours): Forest Soil and Litter		
0	N.D.	N.D.
0.5	0.48	1.01
4.0	0.59	0.31
8.0	0.42	0.21
24.0	1.84	1.20
48.0	0.15	0.09
96.0	1.50	0.85
(Weeks): Forest Soil and Litter		
1	0.51	0.54
2	0.35	0.25
4	0.06	0.07
6	0.06	0.07
9	0.09	0.35
(Weeks): Forest Litter		
12 Sample No. 1	2.75	3.80
Sample No. 2	4.91	3.98
43	N.D.	N.D.
(Weeks): Forest Soil		
12 Sample No. 1	N.D.	0.06
Sample No. 2	N.D.	0.08
43	N.D.	N.D.

* Samples taken at Station SL in sprayed area.

N.D. Not Detectable

Source: Department of Environment. Environment Protection Service. 1975. Effectiveness of stream buffer zones during aerial applications of Chlorophenoxy and Picloram. Herbicide Surveillance Report EPS 5-PR-75-3-39pp.

TABLE 20

TOTAL DUSTFALL[1] (g/m^2 MONTH) IN THE SQUAMISH RIVER ESTUARY

Site	Dates	No. of Samples	Mean	Range	No. Greater Than 5.25[2]	(%)
S-1, Squamish-Mamquam Elementary School	June 1972-July 1974	22	3.3	1.2-6.8	2	9%
S-2, Squamish-Brackendale Elementary School	June 1972-	22	2.1	0.7-5.1	0	0%
S-3, Squamish-School Board Office	July 1972-May 1974	18	3.7	1.3-9.0	4	22%

[1] Source: EQUIS data base, Waste Management Branch, Ministry of Environment

[2] Residential area objective = 5.25 g/m^2 month.

TABLE 21

TOTAL SUSPENDED PARTICULATES[1] ($\mu g/m^3$) IN THE SQUAMISH ESTUARY

(24-HOUR SAMPLES, HIGH VOLUME SAMPLER METHOD)

Site	Dates	No. of Samples	Geometric Mean	Range	No. Greater Than 120[2] (%)	
S-1, Squamish-Mamquam Elementary School	July 1972-Aug. 1974	114	48.7	10-226	10	(9%)
S-2, Squamish-Brackendale Elementary School	July 1972-Aug. 1974	120	23.9	<3-122	1	(< 1%)
S-3, Squamish-School Board Office	July 1972-May 1974	92	60.4	14-244	15	(16%)

[1] Source: EQUIS data base, Waste Management Branch, Ministry of Environment

[2] Federal Government maximum acceptable level - 120 $\mu g/m^3$.

TABLE 22

SULPHATION RATE[1] (mg/dm^2.DAY) FROM MONTHLY SAMPLES IN THE SQUAMISH ESTUARY

Site	Dates	No. of Samples	Average [2]	Range
S-1, Squamish-Mamquam Elementary School	June 1972-Aug. 1974	25	<0.11	<0.1-0.15
S-2, Squamish-Brackendale Elementary School	June 1972-Aug. 1974	25	<0.11	<0.1-0.19
S-3, Squamish-School Board Offices	July 1972-May 1974	21	<0.16	<0.1-0.22

1 Source: EQUIS data base, Waste Management Branch, Ministry of Environment

2 Ontario Standard 0.7 $mg/(dm^2.day)$.

TABLE 23

AMBIENT AIR QUALITY - CHLORINE AND MERCURY LEVELS[1] ($\mu g/m^3$)

SQUAMISH RIVER ESTUARY

Site	Dates	No. of Samples	Mean[2,3]	Range
Chlorine[4]				
S-3, Squamish School Board Office	Nov. 1972-May 1974	-	<7.1	0.4-55.3
Mercury				
S-4, Squamish Health Unit	July 1974-Dec. 1978	901	0.034	<0.001-0.052
S-5, FMC Cell Area[3]	Sept. 1973-Dec. 1978	218	63.3	2.1-245
S-6, FMC, Pemberton Street[4]	July 1973-Mar. 1979	25	0.62	0.02-3.86

[1] Source: EQUIS data base, Waste Management Branch, Ministry of Environment

[2] Pollution Control Board Forest Products Objective for chlorine: 150 $\mu g/m^3$, 24-hour average.

[3] Pollution Control Board Mining Industry Objective for mercury: 1 $\mu g/m^3$, monthly average.

[4] 48-hour sample by impinger

[5] 1 to 5-hour samples by impinger

[6] 5 to 24-hour samples, by impinger

TABLE 24

SUMMARY, RIVERINE WATER QUALITY MONITORING DATA

Site No. and Location	0300194 Squamish River: Above Cheakamus River					0300095 Cheakamus River				0300094 Squamish River Below Cheakamus				B.C. Streams Median Value
Parameters mg/L Unless Specified	Period of Record	No. of Values	Values Max.	Median	Min.	Period of Record	No. of Values	Values Max.	Median	Min.	Period of Record	No. of Values	Values Max.	Median	Min.	
General Ions and Field Parameters																
Alkalinity-Total	1972-1978	23	16.8	10.7	4.8	1972-1979	28	23.8	18.5	11	1972-1979	27	20.8	12.8	5.3	60.5
Calcium-Diss.	1972-1978	23	6	3.3	1.2	1972-1979	28	9.2	6.9	4.2	1972-1979	27	7.8	4.4	1.5	19.2
Chloride	1972-1978	23	3.3	1.4	<0.05	1972-1979	28	3.8	2	0.5	1972-1979	27	5.6	1.8	<0.5	1.2
Hardness	1972-1978	23	17.4	10.4	3.8	1972-1979	28	26.1	20.3	12.6	1972-1979	27	23.6	12.8	4.3	67
Magnesium-Diss.	1972-1978	20	0.78	0.46	0.42	1972-1979	25	0.84	0.63	0.39	1972-1979	26	1	0.55	0.14	4.2
-Total	1972	4	0.73	0.65	0.6	1972	4	0.75	0.69	0.3	1972-1977	4	0.81	0.56	0.27	5.2
Potassium-Diss.	1972	6	1	0.6	0.1	1972	4	0.7	0.6	0.3	1972-1973	5	0.90	0.8	0.3	0.8
Sodium-Diss.	1972-1973	4	3.5	2.6	0.9	1972	2	2.7	2.45	2.2	1972-1973	4	3.5	2.8	0.7	2.5
Sulphate	1972-1973	8	9	5.5	<5	1972-1973	5	8	6	<5	1972-1973	7	8.4	5.2	<5	10.9
Oxygen-Diss.	1972-1978	23	13.9	8.5	7.8	1972-1979	28	16.8	11.2	1.3	1972-1979	27	16.5	11.8	10	10.8
pH	1972-1978	19	7.3	6.9	6.5	1972-1979	24	7.6	7.3	6.9	1972-1979	26	7.4	7	6.6	7.8
Spec. Cond. (µmho/cm)	1972-1978	20	56	24	12	1972-1979	25	73	58	26	1972-1979	24	79	102	15	168
Temperature (°C)	1972-1978	23	13	6.7	1	1972-1979	28	16.8	8.4	0	1972-1979	27	13.2	7	0.5	7.0
Colour and Particulate Matter																
Colour-True (Rel Units)	1972-1973	7	180	5	<5	1972	4	10	5	<5	1972-1973	6	10	5	<5	5
Residue-Non Filterable	1974-1978	15	154	8	2	1974-1979	20	178	4	1	1974-1978	20	148	8.5	2	6
Turbidity (J.T.U)	1972-1974	6	52	2.4	0.2	1972-1974	7	14	2.1	15	1972-1973	5	27	2.4	1.1	2.2

TABLE 24 (CONTINUED)

SUMMARY, RIVERINE WATER QUALITY MONITORING DATA

Site No. and Location	0300092 Stawamus River					0300093 Mamquam River					B.C. Streams Median Value
Parameters mg/L Unless Specified	Period of Record	No. of Values	Values Max.	Median	Min.	Period of Record	No. of Values	Values Max.	Median	Min.	
General Ions and Field Parameters											
Alkalinity-Total	1972-1979	28	11.2	7	0.3	1972-1979	28	21.4	15.1	7.7	60.5
Calcium-Diss.	1972-1979	28	5.4	3	1.3	1972-1979	28	8.5	5.9	2.9	19.2
Chloride	1972-1979	28	1.5	0.7	0.3	1972-1979	28	2.8	1.1	0.5	1.2
Hardness	1972-1979	27	16	8.9	4	1972-1979	28	24.9	17.2	8.4	67
Magnesium-Diss.	1972-1979	25	0.60	0.35	0.16	1972-1979	25	0.89	0.61	0.29	4.2
-Total	1972-1973	4	0.53	0.4	0.2	1972-1973	5	0.83	0.60	0.30	5.2
Potassium-Diss.	1972-1973	4	1.4	0.5	0.1	1972-1973	6	0.90	0.50	0.10	0.8
Sodium-Diss.	1972	2	1.5	1.45	1.4	1972-1973	4	2.4	2.15	0.80	2.5
Sulphate	1972	4	10.2	7.7	<5	1972-1973	8	10.2	6.3	<5	10.9
Oxygen-Diss.	1972-1979	28	15.3	11.1	8.8	1972-1979	28	16.1	11.8	10	10.8
pH	1972-1979	24	7.1	6.7	6.2	1972-1979	26	7.4	7.2	6.7	7.8
Spec. Cond. (umho/cm)	1972-1979	24	50	26	13	1972-1979	25	74.	44.	21	168
Temperature (°C)	1972-1979	28	15.8	7.3	0.5	1972-1979	28	14.9	7.8	0	7.61
Colour and Particulate Matter											
Colour-True (Rel Units)	1972	4	5	5	<5	1972-1973	6	10	5	<5	5
Residue-Non Filterable	1972-1979	20	6	1	<1	1974-1979	20	168	3	1	6
Turbidity (J.T.U.)	1972-1973	7	0.9	0.7	0.2	1972-1973	6	9.6	2.7	0.4	2.2

TABLE 24 (CONTINUED)

SUMMARY, RIVERINE WATER QUALITY MONITORING DATA

Site No. and Location	0300194 Squamish River: Above Cheakamus River					0300095 Cheakamus River					0300094 Squamish River Below Cheakamus					B.C. Streams Median Value
Parameters mg/L Unless Specified	Period of Record	No. of Values	Values Max.	Values Median	Values Min.	Period of Record	No. of Values	Values Max.	Values Median	Values Min.	Period of Record	No. of Values	Values Max.	Values Median	Values Min.	
Nutrients																
Nitrogen																
-Ammonia	1973-1978	19	0.02	0.01	<0.005	1973-1979	24	0.05	0.013	<0.005	1973-1979	24	0.04	0.009	<0.005	0.015
-Nitrate/ Nitrite	1976-1978	5	0.08	0.07	<0.02	1976-1979	9	0.05	0.03	<0.02	1976-1979	10	0.09	0.07	0.02	0.07
-Nitrate	1972-1978	23	0.1	0.07	<0.02	1972-1979	23	0.05	0.03	<0.02	1972-1979	27	0.09	0.07	<0.02	0.07
-Nitrite	1972-1978	23	<0.005	<0.005	<0.005	1972-1979	23	<0.005	<0.005	<0.005	1972-1979	27	<0.005	<0.005	<0.005	0.14
-Organic	1973-1978	12	0.17	0.05	<0.01	1973-1979	17	0.13	0.03	<0.01	1973-1979	17	0.23	0.06	<0.01	-
-Kjeldahl	1972-1978	18	0.17	0.04	<0.01	1972-1979	23	0.25	0.05	<0.01	1972-1979	22	0.25	0.05	<0.01	0.47
Phosphorus																
-Ortho	1973-1978	15	0.004	0.003	<0.003	1974-1979	18	0.011	0.003	0.003	1974-1978	15	0.005	0.003	<0.003	0.005
-Total	1972-1978	27	0.195	0.013	0.003	1972-1979	29	0.149	0.009	0.004	1972-1979	30	0.191	0.012	0.003	0.025
Silica	1972-1973	6	9.9	4.6	2.5	1972	4	10.9	9.6	3.8	1972-1973	5	9.8	7.7	3.1	6.2
Trace Metals and Miscellaneous Toxicants																
Arsenic-Total	1975	2	<0.005	<0.005	<0.005	1975	2	<0.005	<0.005	<0.005	1975	2	<0.005	<0.005	<0.005	0.005
Boron-Diss.	1972-1973	7	<0.2	<0.1	<0.1	1972	4	<0.2	<0.15	<0.1	1972	2	<0.2	<0.1	<0.1	0.1
Chromium-Diss.	1974	2	<0.005	<0.005	<0.005	-	-	-	-	-	1972-1974	3	<0.005	<0.005	<0.005	0.005
-Total	1972-1976	15	0.014	0.005	<0.005	1972-1976	13	0.012	0.005	<0.005	1972-1976	13	0.007	0.005	<0.005	0.005
Copper-Diss.	1974	2	<0.001	<0.001	<0.001	-	-	-	-	-	1974	3	0.002	0.001	<0.001	0.002
-Total	1972-1978	20	0.011	0.002	<0.001	1972-1978	18	0.005	0.001	<0.001	1972-1978	18	0.008	0.001	<0.001	0.002
Cyanide	1975	1	-	<0.01	-	1975	1	-	<0.01		1975	1	-	<0.01		0.01

TABLE 24 (CONTINUED)

SUMMARY, RIVERINE WATER QUALITY MONITORING DATA

Site No. and Location	0300092 Stawamus River					0300093 Mamquam River					B.C. Streams Median Value
Parameters mg/L Unless Specified	Period of Record	No. of Values	Values Max.	Values Median	Values Min.	Period of Record	No. of Values	Values Max	Values Median	Values Min.	
Nutrients											
Nitrogen											
Ammonia	1973-1979	24	0.06	0.007	<0.005	1973-1974	24	0.17	0.007	<0.005	0.015
Nitrate/Nitrite	1976-1979	10	0.26	0.076	0.04	1976-1979	10	0.10	0.02	<0.02	0.07
Nitrate	1972-1979	21	0.26	0.06	0.02	1972-1979	27	0.10	0.02	<0.02	0.07
Nitrite	1972-1979	21	<0.005	<0.005	<0.005	1972-1979	27	<0.005	<0.005	<0.005	0.14
Organic	1973-1979	15	0.12	0.054	<0.01	1973-1979	17	0.20	0.02	<0.01	-
Kjeldahl	1972-1979	22	0.13	0.065	<0.01	1972-1979	23	0.20	0.01	<0.01	0.47
Phosphorus											
Ortho	1974-1978	15	<0.003	0.003	<0.003	1974-1979	18	0.016	0.006	0.003	0.005
Total	1972-1979	28	0.016	0.004	<0.003	1972-1979	32	0.12	0.009	0.003	0.025
Silica	1972	4	9.6	8.3	3.6	1972-1973	6	15.5	11.9	4.7	6.2
Trace Metals and Miscellaneous Toxicants											
Arsenic-Total	-	-	-	-	-	1975	2	<0.005	<0.005	<0.005	0.005
Boron-Diss.	1972	4	<0.2	<0.15	<0.1	1972-1973	7	<0.2	<0.1	<0.1	0.1
Chromium-Diss.	-	-	-	-	-	1972-1974	3	<0.005	<0.005	<0.005	0.005
-Total	1972	4	0.02	0.005	<0.005	1972-1976	13	0.005	0.005	<0.005	0.005
Copper-Diss.	-	-	-	-	-	1974	2	<0.001	<0.001	<0.001	0.002
-Total	1972	4	0.014	0.005	0.001	1972-1978	20	0.009	0.001	<0.001	0.002

TABLE 24 (CONTINUED)

SUMMARY, RIVERINE WATER QUALITY MONITORING DATA

Site No. and Location	0300194 Squamish River: Above Cheakamus River					0300095 Cheakamus River				0300094 Squamish River Below Cheakamus					B.C. Streams Median Value
Parameters mg/L Unless Specified	Period of Record	No. of Values	Values Max.	Median	Min.	Period of Record	No. of Values	Values Max.	Median	Min.	Period of Record	No. of Values	Values Max.	Median	Min.	
Trace Metals and Miscellaneous Toxicants (Con'd)																
Iron-Diss.	1972-1973	8	0.38	0.18	0.06	1972	4	0.32	0.05	0.04	1972-1974	7	0.35	0.11	0.06	0.1
-Total	1973-1978	16	4.5	0.6	0.3	1973-1979	19	2	0.2	<0.1	1973-1979	21	3.6	0.40	0.30	0.3
Lead-Diss.	1974	2	<0.001	<0.001	<0.001	-	-	-	-	-	1972-1974	3	<0.003	0.001	<0.001	0.001
-Total	1972-1978	21	0.008	0.001	<0.001	1972-1979	19	0.006	0.001	<0.001	1972-1978	19	0.01	0.001	<0.001	0.001
Manganese-Diss.	1974	1	-	<0.02	-	-	-	-	-	-	1972-1974	2	0.11	0.07	<0.02	0.02
-Total	1972-1978	18	0.09	0.02	0.01	1972-1978	17	0.04	0.02	<0.01	1972-1978	15	0.08	0.02	<0.01	0.03
Mercury-Diss.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.008
-Total	-	-	-	-	-	-	-	-	-	-	1979	1	-	<0.005	-	0.00005
Molybdenum-Total	1975	1	-	.0005	-	1975	1	-	<0.0005	-	1975	1	-	<0.0005	-	0.0009
Nickel-Diss.	1974	2	<0.01	<0.01	<0.01	-	-	-	-	-	1972-1974	3	<0.01	0.01	<0.01	0.01
-Total	1972-1978	20	0.04	0.01	<0.01	1972-1978	18	0.04	0.012	<0.01	1972-1978	18	0.03	0.01	<0.01	0.01
Phenols	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tannin & Lignin	-	-	-	-	-	-	-	-	-	-	1979	1	-	0.5	-	0.3
Zinc-Diss.	1974	2	<0.005	<0.005	<0.005	-	-	-	-	-	1972-1974	3	<0.005	<0.005	<0.005	0.006
-Total	1972-1978	21	0.011	0.005	<0.005	1972-1978	19	0.009	0.005	<0.005	1972-1978	19	0.014	<0.005	<0.005	0.005
Microbiology																
Coliforms (MPN/100 mL)																
-Fecal	1973-1978	13	10	8*	<2	1973-1979	18	90	8*	<2	1973-1979	18	40	10*	2	23
-Total	1972-1976	12	49	20	11	1972-1976	12	140	23*	7	1972-1976	12	79	24*	11	172

* Geometric Mean

TABLE 24 (CONTINUED)

SUMMARY, RIVERINE WATER QUALITY MONITORING DATA

Site No. and Location	0300092 Stawamus River					0300093 Mamquam River					B.C. Streams Median Value
Parameter mg/L Unless Specified	Period of Record	No. of Values	Values Max.	Median	Min.	Period of Record	No. of Values	Values Max.	Median	Min.	
Trace Metals and Miscellaneous Toxicants											
Cyanide	1975	1	-	<0.01	-	1975	1	-	<0.01	-	0.01
Iron-Diss.	1972	4	0.34	0.05	0.04	1972-1974	8	0.32	0.07	0.02	0.1
-Total	-	-	-	-	-	1973-1979	21	2.2	0.2	<0.1	0.3
Lead-Diss.	-	-	-	-	-	1974	2	<0.001	<0.001	<0.001	0.001
-Total	1972	4	0.004	0.003	<0.003	1972-1978	21	0.026	0.001	<0.001	0.001
Manganese-Diss.	-	-	-	-	-	1974	1	-	<0.02	-	0.02
-Total	1972	4	0.02	0.01	<0.01	1972-1978	18	0.03	0.02	<0.01	0.03
Mercury-Diss.	-	-	-	-	-	-	-	-	-	-	0.008
-Total	-	-	-	-	-	-	-	-	-	-	0.00005
Molybdenum-Total	-	-	-	-	-	1975	1	-	<0.0005	-	0.0009
Nickel-Diss.	-	-	-	-	-	1974	2	<0.01	<0.01	<0.01	0.01
-Total	1972	4	0.08	0.01	<0.01	1972-1978	19	<0.01	<0.01	<0.01	0.01
Phenols	1980	1	-	<0.002	-	-	-	-	-	-	-
Tannin & Lignin	-	-	-	-	-	-	-	-	-	-	0.3
Zinc-Diss.	-	-	-	-	-	1974	2	<0.005	<0.005	<0.005	0.006
-Total	1972	4	0.07	0.005	<0.005	1972-1978	21	0.014	0.005	<0.005	0.005
Microbiology											
Coliforms (MPN/100 mL)											
Fecal	1973-1979	18	240	23*	15	1973-1979	20	540	8	<2	23
Total	1972-1976	12	<2 400	172*	71	1972-1976	14	33	14*	4	172

- No value
* Geometric mean

TABLE 25

A COMPARISON OF PUBLISHED WATER QUALITY CRITERIA FOR AQUATIC LIFE AND DRINKING WATER SUPPLIES

Parameter		Water Quality Criteria[a]					
		EPA (1972)	EPA (1976)	IWD (1972)	IWD (1979) and others[d,e]	Drinking Water Objectives[b]	Receiving Water Objectives[c]
Alkalinity-Total	(mg/L)	30-130	>20	>25	-	-	-
Arsenic	"	0.1	-	0.05	0.05	<0.005-0.05	-
Boron	"	0.75	-	0.50	-	<0.01-5	-
Cadmium	"	0.004	0.0004	.005	0.0002	<0.001-0.005	-
Calcium	"	200	-	75	-	-	-
Chloride	"	-	-	250	-	< 250-250	-
Chromium	"	0.05	0.1	0.05	0.04	< 0.0002-0.05	-
Coliforms-Fecal	(MPN/100 mL)	-	-	-	14[d];200[e]	10[f]-100[g]	-
Coliforms-Total	"	-	-	-	-	100[f]-1000[g]	-
Colour	(Rel. Units)	Max. 75	-	15	-	< 15	-
Copper	(mg/L)	0.002	0.002	.010	0.005	0-1	-
Cyanide	(mg/L)	0.005	0.005	-	0.005	<0.002-0.20	-
Iron, Diss.	"	0.3	1	0.05-0.30	-	<0.05-0.3	-
Lead	"	0.03	-	0.05-0.09	0.010	<0.001-0.05	-
Magnesium	"	12.5	-	50	-		-
Manganese	"	0.05	0.10	0.01	-	<0.01-0.05	-
Mercury	(µg/L)	0.05	0.05	0.10	0.1	<0.002-0.01	-
Molybdenum	(mg/L)	0.01	-		-	-	-

TABLE 25 (CONTINUED)

A COMPARISON OF PUBLISHED WATER QUALITY CRITERIA FOR AQUATIC LIFE AND DRINKING WATER SUPPLIES

Parameter		Water Quality Criteria[a]					
		EPA (1972)	EPA (1976)	IWD (1972)	IWD (1979) and Others[d,e]	Drinking Water Objectives[b]	Receiving Water Objectives[c]
Nickel	(mg/L)	0.2	-	-	-	-	-
Nitrogen-Ammonia	"	0.02	0.016	0.01	-	-	-
Nitrogen-NO_2 + NO_3	"	10	-	10	-	<10	-
Nitrogen-Total		-	-	-	-	-	No detectable increase
Oxygen-Diss.	"		≥5	7.75-9[h]	-	-	<10% decrease
pH	(Rel Units)	6.5-8.5	6.5-9	-	-	6.5-8.	-
Phosphorus-Ortho	(mg/L)	-	-	-	-	<0.2-0.2	-
Phosphorus-Total	(mg/L)	-	0	0.065	-	-	No detectable increase
Turbidity	(JTU)	-	-	<5	-	<1-5	-
Zinc	(mg/L)	-	0.001	0.007	-	< 5 - 5	

[a] Criteria are those considered safe for aquatic biota. All incorporate a safety factor, generally 0.1 to 0.01 times the 96-hr LC_{50} of sensitive species. Refer to individual references for details.
[b] Canadian Drinking Water Standards and Objectives (1968). The range indicates the desirable objectives and maximum or acceptable levels.
[c] Pollution Control Objectives for municipal type waste discharges (1979).
[d] Canadian Shellfish Harvesting Standard. Median not to exceed 14 MPN/100 mL and less than 10% of samples not to exceed 43 MPN/100 mL (Churchland, 1980).
[e] Criteria for swimming; log mean not to exceed 200 MPN/100 mL and less than 10% of samples not to exceed 400 MPN/100 mL (Churchland, 1980).
[f] In 95% of samples in a 30-day consecutive period. Treatment by chlorination required.
[g] In 95% of samples in a 30-day consecutive period. Complete treatment required.
[h] Davis, J.C., 1975.

TABLE 26

RANDOM PAIRS ANALYSIS BETWEEN SAMPLING SITES

Sites Compared	Alkalinity	Calcium	Chloride	Hardness	Magnesium	Dissolved Oxygen	pH	Specific Conductance	Suspended Solids	Turbidity
194 to 095	095>194					N.D.	095>194		194>195	N.D.
194 to 094	094>194 (1975); 094=194 (1972)					N.D.	N.D.	094>194	094>194 (1975) 094=194 (1972)	N.D.
194 to 093	093>194		-	-	-	-	-	-	-	-
194 to 092	-	-	-	-	-	-	-	-	-	-
095 to 094	095>094		N.D.	095>094		094>095 (1976) N.D. (1974, 1972)	095>094		094>095 (1976) N.D. (1974)	N.D.
094 to 093	093>094		094>093	093>094	093>094 (1976) 093=094 (1973)	N.D.	093> 094	093>094 (1976) 093=094 (1972)	093=094 (1976) 094>093 (1973)	N.D.
094 to 092	094>092					N.D.	094>092			-
095 to 093	095>093				N.D. (1976) 095>093 (1972)	093>095	095>093		N.D.	
095 to 092	095>092					N.D.	095>092		095>092 (1976) N.D. (1974)	095>092
093 to 092	093>092								N.D.	

TABLE 26 (CONTINUED)

RANDOM PAIRS ANALYSIS BETWEEN SAMPLING SITES

Sites Compared	Nitrogen					Phosphorus		Iron	Coliforms	
	Ammonia	NO_2/NO_3	Nitrate	Organic	Kjeldahl	Ortho	Total		Fecal	Total
194 to 094	N.D.	N.D.	194>095	N.D.	194=095 (1975) 095>194 (1972)	N.D.	N.D. (1974) 194>095 (1972)	194> 095	095>194	N.D.
194 to 093	← N.D. →									
194 to 092	-	-	-	-	-	-	-	-	-	-
095 to 094	095>094 (1976) N.D. (1974, 1972)	-	094>095	← N.D. →		095>094 (1975) N.D. (1974)	N.D. (1974) 094>095 (1972)	← N.D. →		
094 to 093	← N.D. →		094>093	← N.D. →				094> 093	N.D.	094>093
094 to 092	N.D.	092>094	092>094 (1976) 092=094 (1973)	← N.D. →			094>092	-	← N.D. →	
095 to 093	N.D.	093>095	093>095 (1975) N.D. (1972)	← N.D. →		092>095 (1975) N.D. (1974)	← N.D. →			
095 to 092	N.D.	← 092>095 →		← N.D. →		095>092 (1975) N.D. (1974)	095>092	-	← N.D. →	
093 to 092	N.D.	092>093	092>093 (1975) N.D. (1972)	092>093	← N.D. →			-	← N.D. →	

KEY TO TABLE 26

Site Identification

194 - Squamish River upstream from Cheakamus River

094 - Squamish River downstream from Cheakamus River

095 - Cheakamus River

093 - Mamquam River

092 - Stawamus River

Legend

> Values significantly greater at first site when compared to second site

N.D. - no significant difference between sites

- Not compared, insufficient data

Probability level (p) <0.05 considered significant

TABLE 27

TREND ANALYSIS FOR PERIOD 1972 TO 1979

Parameter	Month	Stawamus River				Mamquam River				Squamish River				Cheakmus River			
		No. of Values	Max.	Mean	Min.	No. of Values	Max.	Mean	Min.	No. of Values	Max.	Mean	Min.	No. of Values	Max.	Mean	Min.
Total Alkalinity	Jan	1	11.2	-	-	1	21.4	-	-	1	20.8	-	-	1	21.4	-	-
	Feb	1	8	-	-	1	18.9	-	-	1	19.7	-	-	1	23.6	-	-
	Mar	4	8.5	7.3	6	4	17.5	16	14	4	18	15.4	14	4	21.7	20	18.5
	Apr	2	6.7	6.4	6	2	16.9	16.2	15.5	2	13.9	13.6	13.2	2	20.2	19.5	18.7
	May	2	7.7	7.6	7.4	2	15	14.6	14.1	2	13	12.3	11.6	3	19.8	17.7	15.6
	June	5	7	5.2	4	5	15.5	11	7.7	5	11.5	7.9	6.5	7	15.7	13.7	12
	July	2	6.9	6.7	6.5	2	11.7	10.6	9.5	1	6.1	-	-	3	14	12.5	11
	Aug	5	8	7.1	5.5	5	14.5	12.4	10.5	5	7.5	6.3	5.3	7	16.2	13.7	12
	Sept	-	-	-	-	-	-	-	-	-	-	-	-	1	15.7	-	-
	Oct	1	8.3	-	-	1	17.1	-	-	1	10	-	-	2	18.5	17.9	17.3
	Nov	2	9.5	8.6	7.7	2	19.9	19.3	18.7	2	17.8	15.3	12.8	4	19	18.1	17.3
	Dec	3	9.3	7.3	6	3	19.3	17.3	15.2	3	19.8	16.9	14.7	3	22.9	20.1	17.9
Total Hardness	Jan	1	16	-	-	1	24.9	-	-	1	23.6	-	-	2	25.8	24.4	23
	Feb	1	12.6	-	-	1	22.1	-	-	1	22.6	-	-	2	26.1	25.8	25.6
	Mar	4	12.6	10.6	9.3	4	20.8	18.7	16.2	4	20.6	17.1	14	8	24	21.9	18.1
	Apr	2	9	8.5	8	2	17.7	17.7	17.6	2	14.2	14.1	13.9	6	21.2	19.7	17.2
	May	2	8	8	8	2	17.5	16.6	15.7	2	14.6	13.7	12.8	5	21.7	20.3	17
	June	5	7.-	6	4.9	5	17.5	12	8.4	5	12	7.6	5.9	10	18.2	15	11.9
	July	2	8	8	8.1	2	12.6	11.8	11	1	5.5	-	-	3	15.7	13.2	12.1
	Aug	5	12	8.9	5.9	5	17	13.8	11	5	6.6	5.3	4.3	12	20.6	13.6	8.3
	Sept	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Oct	1	11.4	-	-	1	19.2	-	-	1	10.5	-	-	2	21.6	19.5	17.5
	Nov	1	13	-	-	2	23	20.3	17.7	2	19	15.6	12.2	6	23	18.2	13.5
	Dec	3	12.5	9.9	7.8	3	26.6	20.6	17.3	3	20.1	17.5	15.8	4	25.7	21.2	18.7

TABLE 27 (CONTINUED)

TREND ANALYSIS FOR PERIOD 1972 TO 1979

Parameter	Month	Stawamus River				Mamquam River				Squamish River				Cheakamus River			
		No. of Values	Max.	Mean	Min.	No. of Values	Max.	Mean	Min.	No. of Values	Max.	Mean	Min	No. of Values	Max.	Mean	Min.
Total Phosphorus	Jan	1	0.004	-	-	1	0.019	-	-	-	-	-	-	2	0.014	0.01	0.005
	Feb	1	0.004	-	-	1	0.009	-	-	-	-	-	-	2	0.008	0.007	0.006
	Mar	4	0.014	0.008	0.005	5	0.009	0.009	0.008	4	0.013	0.012	0.010	8	0.008	0.006	0.004
	Apr	2	0.010	0.007	0.003	2	0.009	0.008	0.007	1	0.011	-	-	8	0.009	0.006	0.004
	May	2	0.004	0.004	0.003	2	0.008	0.007	0.005	1	0.009	-	-	9	0.020	0.008	0.004
	June	5	0.006	0.004	0.003	6	0.02	0.016	0.007	5	0.191	0.08	0.011	14	0.019	0.010	0.003
	July	2	0.004	0.004	0.003	2	0.021	0.015	0.008	-	-	-	-	7	0.019	0.009	0.003
	Aug	5	0.016	0.007	0.003	6	0.11	0.051	0.008	5	0.097	0.078	0.04	21	0.149	0.024	0.003
	Sept	-	-	-	-	-	-	-	-	-	-	-	-	1	0.008	-	-
	Oct	1	0.003	-	-	1	0.009	-	-	-	-	-	-	4	0.009	0.006	0.004
	Nov	3	0.016	0.010	0.003	3	0.011	0.010	0.009	2	0.014	0.010	0.007	11	0.015	0.008	0.005
	Dec	2	0.009	0.008	0.007	3	0.025	0.016	0.01	3	0.047	0.025	0.012	3	0.013	0.011	0.008
Non-Filterable Residue	Jan	1	1	-	-	1	1	-	-	1	2	-	-	2	5	3.5	1
	Feb	1	1	-	-	1	1	-	-	1	2	-	-	2	5	3.5	2
	Mar	2	6	4	2	2	3	2.5	2	2	5	4.5	4	3	2	1.3	1
	Apr	2	1	1	1	2	3	2.5	2	2	8	6.5	5	7	2	1.4	1
	May	2	2	1.5	1	2	4	3.5	3	2	8	6	4	6	4	2.1	1
	June	4	2	1.3	1	4	43	17	2	4	148	65.5	7	10	21	7.7	1
	July	1	1	-	-	1	36	-	-	1	64	-	-	4	26	7.6	2
	Aug	3	3	1.7	1	3	168	76.7	31	3	96	80.3	57	9	178	27.9	1
	Sept	-	-	-	-	-	-	-	-	-	-	-	-	1	3	-	-
	Oct	1	2	-	-	1	5	-	-	1	12	-	-	3	5	2.8	2
	Nov	1	1	-	-	1	2	-	-	1	8	-	-	5	3	2.2	1
	Dec	2	6	3	1	2	2	1.5	1	2	23	16	9	3	3	2	1

TABLE 27 (CONTINUED)

TREND ANALYSIS FOR PERIOD 1972 TO 1979

Parameter	Month	Stawamus River				Mamquam River				Squamish River				Cheakamus River			
		No. of Values	Max.	Mean	Min.	No. of Values	Max.	Mean	Min.	No. of Values	Max.	Mean	Min.	No. of Values	Max.	Mean	Min.
Silica	Jan	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Feb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Mar	1	7.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Apr	-	-	-	-	2	13.5	12.4	11.3	2	9.2	8.5	7.7	1	9.3	-	-
	May	-	-	-	-	-	-	-	-	-	-	-	-	1	8.8	-	-
	June	-	-	-	-	-	-	-	-	-	-	-	-	1	7.2	-	-
	July	1	3.6	-	-	1	4.7	-	-	1	3.1	-	-	1	7.4	-	-
	Aug	1	8.9	-	-	1	5.8	-	-	-	-	-	-	2	4.8	4	3.7
	Sept	-	-	-	-	1	12.5	-	-	1	3.2	-	-	3	10.4	9	7.9
	Oct	-	-	-	-	-	-	-	-	-	-	-	-	1	8	-	-
	Nov	1	9.6	-	-	-	-	-	-	-	-	-	-	1	8.2	-	-
	Dec	-	-	-	-	1	15.5	-	-	1	9.8	-	-	3	9.9	8.9	8.2
Magnesium	Jan	1	0.60	-	-	1	0.89	-	-	1	1	-	-	-	-	-	-
	Feb	1	0.51	-	-	1	0.76	-	-	1	0.89	-	-	2	0.80	0.74	0.68
	Mar	3	0.43	0.40	0.38	3	0.64	0.62	0.6	4	0.72	0.65	0.6	2	0.82	0.8	0.77
	Apr	2	0.37	0.34	0.31	2	0.64	0.63	0.61	2	0.66	0.6	0.52	7	0.69	0.64	0.51
	May	2	0.38	0.31	0.24	2	0.61	0.54	0.47	2	0.57	0.5	0.43	7	0.68	0.62	0.53
	June	5	0.33	0.24	0.16	5	0.62	0.41	0.29	5	0.49	0.3	0.22	5	0.72	0.59	0.43
	July	1	0.27	-	-	1	0.4	-	-	1	0.19	-	-	10	0.53	0.39	0.27
	Aug	4	0.33	0.30	0.22	4	0.49	0.43	0.37	4	0.21	0.18	0.14	2	0.47	0.37	0.26
	Sept	-	-	-	-	-	-	-	-	-	-	-	-	10	0.49	0.33	0.19
	Oct	1	0.41	-	-	1	0.66	-	-	1	0.39	-	-	-	-	-	-
	Nov	2	0.51	0.47	0.42	2	0.83	0.77	0.72	2	0.78	0.7	0.61	2	0.76	0.68	0.6
	Dec	3	0.55	0.41	0.32	3	0.76	0.66	0.56	3	0.76	0.68	0.63	6	0.82	0.53	0.35
														4	0.84	0.66	0.6

- No value.

TABLE 28

ESTIMATED CONCENTRATIONS OF UNDISSOCIATED AMMONIA *

pH	Temp. °C	Percent Un-Ionized Ammonia	Total Ammonia Concentration mg/L									
			.025	.05	.075	.1	.2	.3	.4	.5	1.0	1.5
7.0	0	0.09	-	-	-	-	-	-	-	-	.001	.001
	10	0.19	-	-	-	-	-	.001	.001	.001	.002	.003
	20	0.39	-	-	-	-	.001	.001	.002	.002	.004	.006
7.5	0	0.28	-	-	-	-	.001	.001	.001	.001	.003	.004
	10	0.58	-	-	-	.001	.001	.002	.002	.003	.006	.009
	20	1.22	-	-	.001	.001	.002	.004	.005	.006	.012	.018
8.0	0	0.87	-	-	<.001	.001	.002	.003	.003	.004	.009	.013
	10	1.82	<.001	.001	.001	.002	.004	.005	.007	.009	.018	.027
	20	3.77	.001	.002	.003	.004	.008	.011	.015	.019	.038	.057
8.5	0	2.71	<.001	.001	.002	.003	.005	.008	.011	.014	.027	.041
	10	5.55	.001	.003	.004	.006	.011	.017	.022	.028	.055	.083
	20	11.02	.003	.005	.008	.011	.022	.033	.044	.055	.110	.165
9.0	0	8.10	.002	.004	.066	.008	.016	.024	.032	.041	.081	.121
	10	15.67	.003	.007	.011	.016	.031	.047	.063	.078	.157	.235
	20	28.10	.007	.014	.021	.028	.056	.084	.112	.140	.281	.422

(1) Calculated from equations presented in Clark and Drinnan, in press.

* 0 ppt Salinity

\- Indicates values <0.001 mg/L.

NOTE: Dark line delineates an undissociated ammonia level of 0.02 mg/L. This corresponds to a value of 0.016 mg/L of undissociated ammonia as N.

TABLE 29

MAXIMUM-MINIMUM VALUES AND ANNUAL MEANS OF SELECTED PHYSICAL, CHEMICAL, AND BIOLOGICAL VARIABLES IN THE SURFACE LAYER (0-20 m) OF HOWE SOUND IN 1973 AND 1974

Stn./Yr.	Temp. (°C)	Salinity (‰)	Density (σt)	Dissolved O_2 (mg·ℓ⁻¹)	TNO_3-N (mg·ℓ⁻¹)	TPO_4-P (mg·ℓ⁻¹)	SiO_2 as Si (mg·ℓ⁻¹)	k	Chla (mg·m⁻²)	Primary product (g C·m⁻² y·n⁻¹)
[1]1973	(11.0)	(22.68)	(16.96)	(6.72)	(.127)	(.045)	(1.05)	(.36)	(24.6)	
	6.6-16.2	13.03-27.25	9.09-21.20	5.89-8.57	.010-.343	.012-.075	.71-1.48	.27-.69	0-88.3	299
1974	(10.3)	(21.08)	(17.00)	(7.31)	(.178)	(.060)	(1.14)	(.63)	(41.2)	
	6.0-18.0	11.69-27.05	12.00-21.26	6.10-9.11	.010-.385	.041-.073	.62-1.55	.23-1.33	0-120.3	516
[2]1973	(11.7)	(22.07)	(16.78)	(6.87)	(.104)	(.032)	(.91)	(.38)	(22.9)	
	6.2-16.2	15.39-27.88	12.22-21.68	5.62-8.13	.013-.330	.013-.056	.74-1.11	.24-.60	2.3-77.8	170
1974	(10.1)	(22.60)	(18.19)	(7.34)	(.176)	(.047)	(1.06)	(.41)	(45.0)	
	5.5-17.0	12.84-28.12	12.84-22.05	6.35-8.77	.010-.368	.014-.071	.41-1.56	.21-.77	0.1-157.4	438
[3]1973	(10.9)	(22.14)	(17.27)	(6.69)	(.138)	(.053)	(1.01)	(.42)	(19.7)	
	6.3-16.4	15.35-26.55	11.45-20.73	5.53-9.51	.010-.370	.021-.086	.69-1.36	.26-1.06	0.4-83.7	112
1974	(10.5)	(21.22)	(16.16)	(7.18)	(.147)	(.048)	(.87)	(.40)	(17.9)	
	4.6-16.3	14.40-27.12	10.46-21.19	6.03-9.59	.013-.333	.015-.065	.25-1.65	.23-.60	4.0-47.1	130
[4]1973	(11.3)	(21.43)	(15.81)	(6.54)	(.128)	(.050)	(1.02)	(1.65)	(11.9)	
	6.6-16.8	14.57-26.99	10.70-20.59	5.13-9.14	.008-.345	.019-.080	.72-1.49	.47-3.11	0.4-60.0	10
1974	(10.1)	(21.30)	(16.37)	(6.78)	(.079)	(.048)	(.80)	(2.37)	(15.3)	
	4.8-16.1	13.55-26.72	10.18-21.11	5.81-9.07	.010-.250	.015-.071	.25-1.62	.68-5.30	0.6-45.7	15
[5]1973	(10.1)	(22.83)	(17.25)	(7.20)	(.069)	(.055)	-	(.45)	(11.9)	
	6.3-13.8	15.55-27.19	11.52-21.58	6.43-8.65	.010-.168	.026-.079	-	.18-.87	2.7-29.3	142
1974	(10.4)	(20.24)	(15.35)	(7.39)	(.163)	(.049)	(1.01)	(.34)	(18.0)	
	4.5-15.1	13.62-29.52	9.85-20.49	5.30-9.63	.010-.350	.013-.070	.18-1.66	.20-.54	1.4-47.4	181
[6]1973	(10.6)	(22.24)	(17.06)	(7.50)	(.059)	(.051)	-	(.41)	(13.5)	
	6.2-15.5	18.18-26.52	13.70-20.87	6.79-8.89	.010-.171	.010-.075	-	.28-.54	2.8-35.1	85
1974	(9.5)	(19.83)	(15.40)	(7.36)	(.194)	(.046)	(1.06)	(.49)	(13.1)	
	4.4-14.0	11.34-26.07	9.16-20.63	5.88-9.36	.017-.311	.018-.066	.25-1.64	.20-1.01	0.5-44.3	109
[7]1973	(10.9)	(24.19)	(17.50)	(6.55)	(.139)	(.051)	(1.03)	(.50)	(10.9)	
	6.7-15.2	16.86-29.16	12.49-21.33	5.18-9.27	.020-.303	.017-.076	.42-1.48	.24-.82	0.1-78.6	69
1974	(8.8)	(21.73)	(16.74)	(6.53)	(.158)	(.050)	(1.02)	(1.02)	(14.4)	
	5.3-14.6	10.87-26.25	7.96-20.00	5.67-8.14	.013-.295	.024-.073	.28-1.75	30-2.64	0.7-41.1	103
[8]1973	(9.8)	(20.80)	(15.53)	(6.71)	(.120)	(.058)	(1.08)	(1.00)	(14.1)	
	5.9-13.9	11.66-27.87	8.79-19.86	5.45-9.22	.013-.277	.020-.089	.55-1.67	.62-1.56	0.3-92.1	42
1974	(8.4)	(19.76)	(15.34)	(6.39)	(.125)	(.055)	(.98)	(1.71)	(7.8)	
	4.8-12.5	10.87-25.53	8.74-20.10	5.71-7.25	.027-.207	.036-.092	.45-1.50	.97-2.10	1.2-18.1	37

TABLE 29 (CONTINUED)

Stn./Yr.	Temp. (°C)	Salinity (‰)	Density (σt)	Dissolved O_2 (mg·ℓ⁻¹)	NO_3-N (mg·ℓ⁻¹)	PO_4-P (mg·ℓ⁻¹)	SiO_2 as Si (mg·ℓ⁻¹)	k	Chla (mg·m⁻²)	Primary Product (g C·m⁻²·u·τ⁻¹)
9 1973	9.51	(22.31)	(15.72)	(6.67)	(.111)	(.052)	(1.07)	(.81)	(11.1)	
	5.9-13.7	6.67-29.69	4.79-20.82	5.19-11.51	.010-.307	.026-.80	.76-1.14	.19-1.89	0-124.0	76
1974	(8.5)	(29.25)	(15.67)	(6.17)	(.192)	(.046)	(1.33)	.59)	(8.2)	
	5.0-12.9	5.77-26.29	4.25-20.27	4.88-8.15	.020-.361	.012-.071	.50-2.02	.19-1.85	0.4-14.2	69
10 1973	(8.8)	(22.15)	(15.78)	(6.86)	(.120)	(.062)	(1.00)	(.78)	(12.1)	
	5.2-12.6	7.00-29.75	5.11-20.56	5.31-11.21	.010-.300	.033-.095	.71-1.52	.26-2.76	0.3-116.2	108
1974	(7.8)	(19.13)	(14.82)	(6.71)	(.203)	(.046)	(1.42)	(1.23)	(9.3)	
	4.5-12.1	7.83-25.88	5.85-18.66	1.83-8.17	.039-.395	.021-.066	.68-2.02	.32-2.99	1.0-22.1	57

Data from Stockner et al.(1977)

Station locations are shown in Figure 27

Table 30
1980 Field Survey
Mamquam Blind Channel

Dissolved Oxygen (Corrected For Salinity)

Site Number (Indicated in Figure 31)

Depth (m)	1		2		3		4		5		6		7		8	
	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26
Surface	9.4	7.4	8.4	8.9	9.3	8.5	8.9	8.6	9.6	9.0	9.8	9.7	9.9	10.1	10.5	10.0
0.5								8.3		8.6		9.7		9.6		9.9
1.0	8.9		8.3		8.5	8.3	8.9	8.1	9.5	8.3	9.4	9.0	9.4	9.1	10.3	9.7
1.5	8.9		8.2		8.4	[illegible]	8.5	8.0	9.4	8.2	9.2	8.[illegible]	9.4	8.8	10.1	9.5
2.0	8.2		8.0		8.1	7.5	8.[illegible]	[illegible].5	9.3	8.2	9.0	8.3	9.4	8.5	9.7	8.7
2.5					7.8	6.9	8.[illegible]	[illegible].1	9.2	8.1	8.8	8.2	9.1	8.3	9.5	8.4
3.0					[illegible].[illegible]	6.5*	8.5	6.6	8.6	[illegible].9	8.8	8.2	9.1	8.2	9.3	8.2
3.5					7.6		8.2		8.6		8.8			8.0		8.1
4.0					[illegible].6		8.2		8.5		8.8			7.7		7.8
4.5					[illegible].1		7.0		8.2		8.8					
5.0					6.9*		6.7		[illegible].2		8.[illegible]					
5.5							6.9		[illegible].4		9.2					
6.0							[illegible].1		[illegible].[illegible]							
6.5							6.6		8.1*							
7.0							6.0									

* Bottom

TABLE 30 (CONTINUED)

1980 Field Survey

Mamquam Blind Channel

Percent Saturation

Site Number (Indicated in Figure 31)

Depth (m)	1		2		3		4		5		6		7		8	
	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26
Surface	94	72.4	84	87.3	91.8	81	87.1	81.9	93.9	85.3	95.7	88.3	96.9	92.9	103.7	93
0.5								79		81.5		89.6		89.3		92.1
1.0	88.5		83		83.7	79	87.1	77.1	93	78.7	91.5	83.2	92	84.9	101.5	90.5
1.5	88.5		81.5		82.9	73.5	83.2	76.2	92	77.7	89.6	81.2	92	82.2	99.5	88.6
2.0	81.1		79.3		79.8	72.1	85	71.4	91	77.7	87.6	77.6	91.4	79.4	94.7	81.3
2.5					76.7	66.6	85	67.7	89.8	76.8	85.7	77.2	88.5	77.8	92.3	77.1
3.0					75.7	62.6*	85	63.2	84	74.9	85.5	77.2	88.5	76.9	90.2	76.9
3.5					74.5		80.1		81		85.5			75.1		75.9
4.0					69		80.1		80.8		85.1			72.5		73.1
4.5					66.9*		68.5		79.8		85.1					
5.0							65.6		70.5		84					
5.5							67.2		72.1		88.6					
6.0							68.9		74.5							
6.5							63.6		78*							
7.0							57.7									

TABLE 30 (CONTINUED)

1980 Field Survey

Mamquam Blind Channel

Temperature (°C)

Site Number (Indicated in Figure 31)

Depth (m)	1		2		3		4		5		6		7		8	
	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26
Surface	13.9	12.9	13.9	13.1	13.3	11.7	12.9	11.7	12.9	11.5	12.8	9.8	12.9	10.2	13.3	10.7
0.5					13.1			11.7		11.5		10.1		10.7		10.7
1.0	13.6		13.9		13.2	11.7	12.9	11.7	12.9	11.5	12.7	10.4	12.9	10.8	13.2	10.8
1.5	13.6		13.6		13.3	11.8	12.9	11.7	12.9	11.5	12.7	10.8	12.9	10.9	13.2	10.8
2.0	13.4		13.5		13.2	12.1	12.8	11.7	12.9	11.5	12.7	10.9	12.6	10.9	12.8	10.9
2.5					13.1	12.3	12.8	11.8	12.8	11.5	12.7	11.2	12.5	11.0	12.6	10.9
3.0					13.1	12.2*	12.8	11.9	12.8	11.5	12.6	11.2	12.5	11.0	12.5	11.0
3.5					13.0		12.8		12.8		12.6			11.1		11.0
4.0					12.6		12.8		12.7		12.4			11.2		11.0
4.5					12.3*		12.9		12.7		12.4					
5.0							12.9		12.9		12.3					
5.5							12.7		12.7		12.2					
6.0							12.5		12.3							
6.5							12.2		12.2*							
7.0							12.1									

* Bottom

TABLE 30 (CONTINUED)
1980 Field Survey
Mamquam Blind Channel

Salinity (ppt)

Site Number (Indicated in Figure 31)

Depth (m)	1		2		3		4		5		6		7		8	
	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26
Surface	6.0	4.9	6.0	3.9	6.0	2.9	6.0	3.8	5.6	3.2	4.4	1.6	3.4	1.4	3.4	1.9
0.5								3.8		3.6		2.1		2.6		2.1
1.0	6.0		6.8		6.0	3.1	6.0	3.9	5.6	3.7	5.0	2.8	3.8	2.8	3.4	2.3
1.5	6.0		6.8		6.8	3.4	6.0	4.1	5.6	3.8	6.0	3.2	4.4	3.1	3.8	3.6
2.0	6.8		6.8		6.8	3.9	6.0	4.2	5.6	3.8	6.0	3.4	5.6	3.2	5.0	2.8
2.5					7.3	4.1	6.0	5.6	5.6	4.0	6.0	3.9	5.6	3.5	5.6	3.1
3.0					7.3	7.1*	6.0	6.7	5.6	4.5	6.0	4.1	6.0	3.6	6.8	3.2
3.5					7.3		6.8		6.0		6.8			3.8		3.4
4.0					7.9		7.3		6.0		6.8			4.8		3.7
4.5					7.9		7.3		6.8		7.3					
5.0					8.6*		7.9		7.3		9.2					
5.5							9.2		7.9		11.3					
6.0							9.7		8.6							
6.5							11.3		9.7*							
7.0							11.5									

*Bottom

TABLE 30 (CONTINUED)
1980 Field Survey
Mamquam Blind Channel

pH

Site Number (Indicated in Figure 31)

Depth (m)	1		2		3		4		5		6		7		8	
	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26	80/06/24	80/06/26
Surface	6.9	6.9	6.9	6.8	7.0	6.7	7.0	6.7	7.0	6.8	6.9	6.7	6.9	6.7	7.1	6.8
0.5								6.7		6.7		6.7		6.7		6.8
1.0	6.9		6.9		7.0	6.7	7.0	6.7	7.0	6.7	7.0	6.7	6.9	6.7	7.1	6.8
1.5	6.9		6.9		6.9	6.7	7.0	6.6	7.0	6.7	7.0	6.7	6.9	6.7	7.1	6.8
2.0	6.9		6.9		6.9	6.6	7.0	6.6	7.0	6.7	7.0	6.6	7.0	6.7	7.0	6.7
2.5					6.9	6.5	7.0	6.6	7.0	6.7	7.0	6.6	7.0	6.6	7.0	6.6
3.0					6.9	6.5*	6.9	6.6	7.0	6.7	7.0	6.7	7.0	6.6	7.0	6.6
3.5					6.9		6.9		7.0		7.0			6.6		6.6
4.0					6.9		6.9		6.9		7.0			6.6		6.6
4.5					6.9		6.9		6.9		7.0					
5.0					6.9*		6.9		6.9		7.1					
5.5							6.8		6.8		7.3					
6.0							6.9		7.0							
6.5							6.9		7.1*							
7.0							6.9									

* Bottom

TABLE 31

CHEMICAL ANALYSES OF SURFACE WATER SAMPLES OBTAINED FROM HOWE SOUND[a]

SAMPLE	DISSOLVED NO_2-NO_3 mg/ L	DISSOLVED PO_4 mg/L	TOTAL P mg/L	CONDUCTIVITY umhos/cm	pH	ALKALINITY $CaCO_3$ mg/L	CALCIUM mg/L as Ca++	HARDNESS mg/L as $CaCO_3$	TURBIDITY J.T.U.
STATION 1	0.05	< 0.003	0.025	5 200	7.05	14.9	70.6	564	25
STATION 2	0.04	< 0.003	0.016	5 080	6.08	14.9	98	530	6.4
STATION 3	0.02	< 0.003	0.030	28.4	6.50	4.5	2.4	8.1	36
STATION 4	0.07	<0.006	0.014	11 000	7.05	26.9	94.1	1 190	6.7
STATION 5	0.09	0.010	0.018	14 600	7.35	34.9	172	1 603	5.4
STATION 6	0.09	0.007	0.013	14 100	7.40	34.4	169	1 552	4.7
STATION 7	0.01	< 0.003	0.023	17 500	7.95	45.8	259	2 016	1.6

[a] Analyses conducted by the Department of Environment, Water Quality Laboratory, Vancouver, B. C. Reported in Cliff and Stockner, 1973

LEGEND: Nutrient Analyses, Station Locations
1. Directly off of the Squamish River mouth.
2. Directly off of the Mamquam Blind Channel.
3. Squamish River water.
4. Adjacent to Watts Point.
5. Centre channel between Britannia and Woodfibre.
6. Sill, midway between Porteau and Defence Island.
7. Adjacent to Anvil Island reef.

TABLE 32

NUTRIENT CONCENTRATIONS (µg-at /L)[1] IN TIDAL CREEKS IN THE CENTRAL DELTA (SEE FIGURE 33 FOR SAMPLING LOCATIONS)

CREEK[2] LEVEL	NO_3^-		NH_4^+		PO_4^{-3}		pH
	PILE	SNAG	PILE	SNAG	PILE	SNAG	
1974							
19 July							
H	2.41	1.83	4.14	7.19	1.32	1.19	6.98
M	2.77	2.17	3.10	9.41	0.99	0.79	6.90
L	2.01	1.92	4.92	6.03	1.17	1.02	6.94
02 September							
H	0.50	0.21	3.40	5.71	2.30	1.72	7.08
M	1.12	0.74	3.90	6.33	2.49	1.98	7.12
L	0.74	0.37	2.49	5.46	1.90	1.32	7.10
1975							
22 January							
H	31.40	-	1.74	-	4.39	-	7.66
M	39.90	27.29	3.12	3.98	4.90	3.17	7.55
L	33.71	21.07	2.94	3.14	4.19	2.88	7.58
19 April							
H	3.93	4.39	1.39	2.75	0.94	1.19	7.67
M	4.80	5.12	2.43	3.91	1.32	1.98	7.62
L	4.17	4.72	2.01	3.49	0.89	0.94	7.69
12 June							
H	1.92	1.35	6.21	9.42	9.72	1.12	7.15
M	4.71	2.99	7.49	12.31	0.91	1.40	7.16
L	3.12	2.42	5.12	9.99	0.61	1.19	7.19

[1] Source: Pomeroy (1977); µg-at/L are µg-atoms/litre

[2] H = just below delta surface
M = mid creek level
L = creek bottom

TABLE 33

UNDISSOCIATED AMMONIA VALUES AT 20 PPT SALINITY

pH	Temp. °C	Percent Unionized Ammonia	Total Ammonia Concentration (m g/L)														
			.1	.2	.3	.4	.5	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
7.0	0	0.08	-	-	-	-	-	0.001	0.002	0.002	0.003	0.004	0.005	0.006	0.006	0.007	0.008
	10	0.16	-	-	-	-	0.001	0.002	0.003	0.005	0.006	0.008	0.009	0.011	0.013	0.014	0.016
	20	0.34	-	-	-	0.001	0.002	0.003	0.007	0.010	0.014	0.017	0.020	0.024	0.027	0.030	0.034
7.5	0	0.24	-	-	-	-	0.001	0.001	0.002	0.005	0.007	0.010	0.012	0.014	0.017	0.019	0.022	0.024
	10	0.51	-	-	0.001	0.002	0.003	0.005	0.010	0.015	0.020	0.026	0.030	0.036	0.041	0.046	0.051
	20	1.08	0.001	0.002	0.003	0.004	0.005	0.010	0.022	0.032	0.043	0.054	0.065	0.076	0.086	0.097	0.108
8.0	0	0.77	0.001	0.002	0.002	0.003	0.004	0.008	0.015	0.023	0.031	0.039	0.046	0.056	0.062	0.069	0.077
	10	1.61	0.002	0.003	0.005	0.006	0.008	0.016	0.032	0.048	0.064	0.081	0.097	0.113	0.129	0.145	0.161
	20	3.33	0.003	0.007	0.010	0.013	0.017	0.033	0.067	0.100	0.133	0.167	0.200	0.233	0.266	0.300	0.333
8.5	0	2.39	0.002	0.005	0.007	0.010	0.012	0.024	0.048	0.071	0.096	0.120	0.143	0.167	0.191	0.215	0.239
	10	4.91	0.004	0.008	0.013	0.017	0.020	0.042	0.084	0.126	0.168	0.210	0.295	0.344	0.393	0.442	0.419
	20	9.82	0.009	0.019	0.028	0.037	0.046	0.093	0.186	0.278	0.371	0.464	0.589	0.687	0.786	0.884	0.928

(1) Calculated from equations presented in Clark and Drinnan, in press.

NOTE: Dark line delineates an undissociated ammonia level of 0.02 mg/L. This corresponds to a value of 0.016 mg/L of undissociated ammonia as N.

TABLE 34

MERCURY AND TOTAL ORGANIC CARBON IN WATER

FMC MARSH AND CATTERMOLE CREEK

JUNE 13, 1980

	Station Number	Mercury (μ g/L)	Total Organic Carbon (mg/L)	pH
FMC MARSH	1	0.5	22	
	2	1.2	38	6.7
	3	2.4	44	7.0
	4	2.62	31	7.6
	5	0.27	25	6.9
	6	0.4	35	6.9
	7	0.35	25	6.9
	8	0.66	14	6.9
	Mean	1.05	29.3	6.9 *
CATTERMOLE CREEK	1	0.33	6	7.6
	2	0.73	-	-
	3	1.15	-	-
	4	0.33	6	7.5
	5	0.43	6	7.3
	6	0.25	-	7.8
	7	0.13	6	7.4
	8	0.35	3	7.5
	Mean	0.46	5.4	7.5 *

* Median Value

\- no value

TABLE 35

MERCURY CONCENTRATIONS IN WATER

Location	Date	Depth (m)	Mercury Concentrations (µg/L)		
			Particulate	Dissolved	Total
chlor-alkali plant-outfall	1972	surface	0.059	0.111	0.170
near chlor-alkali plant	1972	surface	0.027	0.086	0.113
chlor-alkali plant-Barge dock	1972	surface	0.039	0.118	0.157
chlor-alkali plant-barge dock out 100'	1972	surface	0.053	0.125	0.178
Squamish outer harbour	1972	surface	0.024	0.082	0.106
mid-channel off Furry Creek	1972	surface	-	-	< 0.05[1]
Britannia	1972	surface	0.032	0.075	0.107
Britannia	1972	250	0.037	0.144	0.181
Woodfibre pulpmill (0.4 km offshore)	1977	surface	-	-	< 0.05[1]
Gambier Island	1972	surface	0.048	0.186	0.234
chlor-alkali plant-west	1972	surface	0.058	-	-
chlor-alkali plant-central	1972	surface	0.076	-	-
chlor-alkali plant-east	1972	surface	0.020	-	-
Port Mellon	1972	88	0.011	-	-
Port Mellon	1972	46	0.010	-	-
Port Mellon	1972	0	0.011	-	-

Sources: Thompson, J.A.J. and F.T. McComas. 1973. Distribution of mercury in the sediments and waters of Howe Sound, British Columbia. FRBC Tech. Report #396. 31pp.

[1] Garrett, C. et al.; In press.

TABLE 36

SEDIMENT SIZE DISTRIBUTION MAMQUAM BLIND CHANNEL

Sieve Mesh (μ)	Ø	Station 1		Station 2		Station 3		Station 4	
		%	Cum. %	%	Cum. %	%	Cum. %	%	Cum. %
1 190	-.25	2.8	2.8	52.8	52.8	9.6	9.6	4.3	4.3
590	.76	4.9	7.7	40.2	93.0	18.1	27.7	14.7	19.0
297	1.75	17.7	25.4	6.1	99.1	21.3	49.0	35.7	54.7
149	2.75	41.3	66.7	0.6	99.7	20.7	69.7	27.7	82.4
105	3.25	13.8	80.5	0.3	100.0	9.6	79.3	6.9	89.3
74	3.76	10.8	91.3	<0.3		9.0	88.3	5.2	94.5
53	4.24	4.1	95.4	<0.3		7.4	95.7	2.9	97.4
37	4.76	3.1	98.5	<0.3		3.6	99.3	2.0	99.4
<37	(>4.76)	1.5	100.0	<0.3		0.7	100.0	0.6	100.0

Sieve Mesh (μ)	Ø	Station 5		Station 6		Station 7		Station 8	
		%	Cum. %	%	Cum. %	%	Cum. %	%	Cum. %
1 190	-.25	15.8	15.8	23.2	23.2	25.5	25.5	21.2	21.2
590	.76	32.7	48.5	24.8	48.0	39.7	65.2	35.4	56.6
297	1.75	19.1	67.6	23.5	71.5	23.4	88.6	22.1	78.7
149	2.75	16.4	84.0	21.5	93.0	5.7	94.3	9.1	87.8
105	3.25	4.1	88.1	3.2	96.2	1.4	95.7	3.2	91.0
74	3.76	3.7	91.8	1.8	98.0	1.8	97.5	2.6	93.6
53	4.24	3.4	95.2	1.2	99.2	1.4	98.9	2.2	95.8
37	4.76	3.1	98.3	0.8	100.0	0.7	99.6	2.2	98.0
<37	(>4.76)	1.8	100.0	<0.4		0.4	100.0	2.0	100.0

TABLE 36 (CONTINUED)

SEDIMENT SIZE DISTRIBUTION MAMQUAM BLIND CHANNEL

Sieve Mesh (μ)	Ø	Station 9		Station 10		Station 11		Station 12	
		%	Cum. %	%	Cum. %	%	Cum. %	%	Cum. %
1 190	-.25	22.3	22.3	23.3	23.3	14.7	14.7	5.8	5.8
590	.76	32.1	54.4	32.3	55.6	26.1	40.8	21.7	27.5
297	1.75	22.3	76.7	18.0	73.6	25.0	65.8	27.7	55.2
149	2.75	14.3	91.0	10.5	84.1	11.7	77.5	15.4	70.6
105	3.25	3.6	94.6	3.8	87.9	4.6	82.1	6.6	77.2
74	3.76	2.7	97.3	4.5	92.4	5.9	88.0	6.7	83.9
53	4.24	0.9	98.2	3.0	95.4	4.1	92.1	5.3	89.2
37	4.76	1.8	100.0	3.0	98.4	4.1	96.3	5.1	94.3
<37	(>4.76)	<1.0		1.6	100.0	3.7	100.0	5.7	100.0

Sieve Mesh (μ)	Ø	Station 13		Station 14		Station 15		Station 16	
		%	Cum. %	%	Cum. %	%	Cum. %	%	Cum. %
1 190	-.25	27.8	27.8	11.5	11.5	2.6	2.6	2.6	2.6
590	.76	31.5	59.3	23.7	35.2	12.3	14.9	10.6	13.2
297	1.75	30.2	89.5	26.6	61.8	19.0	33.9	15.9	29.1
149	2.75	7.7	97.2	17.3	79.1	16.0	49.9	12.5	41.6
105	3.25	1.4	98.6	6.5	85.6	7.4	57.3	6.6	48.2
74	3.76	0.9	99.5	5.8	91.4	9.7	67.0	10.1	58.3
53	4.24	0.3	99.8	2.9	94.3	7.6	74.6	11.5	69.8
37	4.76	0.2	100.0	3.6	97.9	9.8	84.4	13.5	83.3
<37	(>4.76)	<0.2	100.0	2.1	100.0	15.6	100.0	16.7	100.0

TABLE 36 (CONTINUED)

SEDIMENT SIZE DISTRIBUTION MAMQUAM BLIND CHANNEL

Sieve Mesh (μ)	Ø	Station 17		Station 20		Station 22		Station 23	
		%	Cum. %	%	Cum. %	%	Cum. %	%	Cum. %
1 190	-.25	7.7	7.7	9.2	9.2	3.5	3.5	0.7	0.7
590	.76	14.3	22.0	41.1	50.3	11.2	14.7	2.9	3.6
297	1.75	11.9	33.9	41.7	92.0	16.1	30.8	7.8	11.4
149	2.75	9.4	43.3	6.9	98.9	23.2	54.0	28.4	39.8
105	3.25	5.6	48.9	0.7	99.6	11.9	65.9	14.4	54.2
74	3.76	10.7	59.6	0.2	99.8	12.2	78.1	14.0	68.2
53	4.24	19.2	78.8	0.1	99.9	8.1	86.2	8.1	73.3
37	4.76	14.6	93.4	0.1	100.0	6.5	92.7	8.1	84.4
<37	(>4.76)	6.6	100.0	<0.1		7.3	100.0	15.6	100.0

Note: Sampling locations are indicated in Figure 36.

$$\text{Ø} = \frac{-\log_{10} y}{0.301}$$ where y = particle diameter (mm)

TABLE 37

SEDIMENT SIZE DISTRIBUTION CATTERMOLE CREEK

Sieve Mesh (μ)	Ø	Station 24		Station 25		Station 26		Station 27	
		%	Cum. %	%	Cum. %	%	Cum. %	%	Cum. %
1 190	-.25	2.9	2.9	4.5	4.5	0.5	0.5	7.6	7.6
590	.76	14.9	17.8	30.4	34.9	3.1	3.6	36.5	44.1
297	1.75	29.8	47.6	41.0	75.9	6.8	10.4	40.5	84.6
149	2.75	24.4	72.0	15.5	91.4	10.9	21.3	12.3	96.9
105	3.25	9.9	81.9	3.6	95.0	11.6	32.9	1.4	98.3
74	3.76	9.9	91.8	2.8	97.8	19.8	52.7	0.9	99.2
53	4.24	4.2	96.0	0.9	98.7	15.7	68.4	0.4	99.6
37	4.76	3.0	99.0	0.9	99.6	14.7	83.1	0.3	99.9
<37	(>4.76)	1.0	100.0	0.4	100.0	16.9	100.0	0.1	100.0

Sieve Mesh (μ)	Ø	Station 28		Station 29		Station 30		Station 31	
		%	Cum. %	%	Cum. %	%	Cum. %	%	Cum. %
1 190	-.25	3.0	3.0	5.0	5.0	1.4	1.4	6.2	6.2
590	.76	18.1	21.1	31.6	36.6	4.9	6.3	28.6	34.8
297	1.75	30.8	51.9	41.2	77.8	7.7	14.0	45.7	80.5
149	2.75	17.0	68.9	17.2	95	10.5	24.5	16.1	96.6
105	3.25	8.2	77.1	2.8	97.8	8.9	33.4	1.5	98.1
74	3.76	9.7	86.8	1.3	99.1	16.5	49.9	0.8	98.9
53	4.24	5.7	92.5	0.4	99.5	17.8	67.7	0.4	99.3
37	4.76	4.5	97.0	0.3	99.8	17.0	84.7	0.4	99.7
<37	>4.76	3.0	100.0	0.2	100.0	15.3	100.0	0.3	100.0

TABLE 37 (CONTINUED)

SEDIMENT SIZE DISTRIBUTION CATTERMOLE CREEK

Sieve Mesh (μ)	Ø	Station 32		Station 33		Station 34	
		%	Cum. %	%	Cum. %	%	Cum. %
1 190	-.25	11.1	11.1	4.8	4.8	7.5	7.5
590	.76	30.0	41.1	20.6	25.4	18.3	25.8
297	1.75	29.3	70.4	27.3	52.7	16.3	42.1
149	2.75	14.3	84.7	15.9	68.6	15.9	58.0
105	3.25	4.7	89.4	5.1	73.7	8.6	66.6
74	3.76	4.4	93.8	5.2	78.9	10.2	76.8
53	4.24	2.2	96.0	6.7	85.6	7.7	84.5
37	4.76	2.3	98.3	7.9	93.5	8.3	92.8
<37	(>4.76)	1.7	100.0	6.5	100.0	7.2	100.0

$$\text{Ø} = \frac{-\log_{10} y}{0.301}$$ where y = particle diameter (mm)

TABLE 38

SUMMARY, SEDIMENT CHARACTERISTICS

MAMQUAM BLIND CHANNEL

Sample Location	Median Particle Diameter (μ)	Quartile Deviation (QD_{ϕ})	Quartile Skewness ($Sk_q\phi$)	Remarks
1	199.	0.69	0.07	Core sample - top 10 cm
2	1 231.	0.58	-0.04	" "
3	282.	1.53	0.45	" "
4	325.	0.74	0.02	" "
5	535.	0.90	0.40	" "
6	489	1.21	0.04	" "
7	678.	0.70	-0.12	" "
8	650.	0.99	0.52	" "
9	647.	0.93	0.16	Grab sample - top 10 cm
10	678.	1.04	0.32	" "
11	473.	1.20	0.26	" "
12	342.	1.23	0.28	" "
13	708.	1.46	-0.04	" "
14	390.	1.07	-0.04	Grab sample - strong H_2S some wood fibre
15	149.	1.49	0.04	" "
16	100.	1.53	-0.26	" "
17	102.	1.65	-0.68	" "
18	-	-	-	Grab interfered by wood-bark
19	-	-	-	" "
20	607.	0.59	0.	Grab sample - top 10 cm
21	-	-	-	Grab wouldn't take hold
22	164.	1.13	0.21	Grab sample - top 10 cm
23	115.	0.90	0.08	" "

$QD\phi = (Q_3\phi - Q_1\phi)/2$

$S_{kq}\phi = \left[(Q_1\phi + Q_3\phi)/2\right] - Md\phi$

$Md\phi$ = median value in phi units

$Q_3\phi$ = ϕ value at 75%

$Q_1\phi$ = ϕ value at 25%

$Q = -\log_{10}y(mm)/0.301$

$\phi = \frac{\log_{10}y}{0.301}$

TABLE 39

SUMMARY, SEDIMENT CHARACTERISTICS

CATTERMOLE CREEK

Sample Location	Median Diameter		Phi Quartile Deviation QDØ	Phi Quartile Skewness $Sk_q\phi$
	Ø	μ		
24	1.82	283	0.92	0.17
25	1.18	441	0.64	-0.12
26	3.64	80	0.76	0.06
27	0.90	536	0.67	0.01
28	1.70	307	1.12	0.31
29	0.97	511	0.66	0.07
30	3.76	74	0.86	-0.10
31	1.18	441	0.54	-0.14
32	1.04	486	0.77	0.27
33	1.65	319	0.85	0.93
34	2.26	208	0.99	0.45

TABLE 40

SEDIMENT ANALYSES (1980)

CATTERMOLE CREEK AND FMC MARSH

FMC Marsh			Cattermole Creek			Mamquam Blind Channel	
Station No.*	Mercury (µg/g) Dry	Total Organic Carbon (µg/g) Dry	Station No.**	Mercury (µg/g) Dry	Total Organic Carbon (µg/g) Dry	Station No.**	Total Organic Carbon (µg/g) Dry
2	2.73	6.0	24	0.36	0.5	1	11.3
						2	17.1
3†	3.44†	6.8†	25	0.31	0.6	3	20.7
						4	15.0
3†	10.5†	8.9†	26	2.14	5.0	5	9.4
						6	7.9
3†	11.3†	11.0†	27	-	-	7	7.9
						8	16.0
4†	2.71†	9.3†	28	0.59	0.6	9	9.7
						10	20.2
4†	2.78†	6.9†				11	11.3
4†	2.84†	8.3†	29	3.4	2.8	12	23.0
5	2.72	6.0	30	1.2	7.0	13	6.4
						14	57.9
6	9.13	4.7	31	-	-	15	67.0
						16	30.0
7	2.45	11.0	32	0.5	3.3	17	48.1
						20	7.6
8	1.93	5.4	33	0.46	1.7	22	20.0
9	3.23	11.0	34	0.99	0.7	23	11.0

† Replicate analyses
* Station locations indicated in Figure 35
** Station locations indicated in Figure 36

TABLE 41

MERCURY CONTENT OF SEDIMENT GRAB SAMPLES IN HOWE SOUND

Station (c)	Depth (a) meters	(b) Hg µg/g dry wt. $\bar{X}$	n^b	range
1	36	0.09	2	0.043-0.14
2	20	0.14	2	0.041-0.24
3	17	0.11	2	0.11 -0.12
4	48	0.17	2	0.12 -0.23
5	6	0.25	2	0.64 -0.87
6	40	0.58	2	0.55 -0.61
7	59	0.094	2	0.092-0.097
8	50	0.11	2	0.083-0.14
9	90	0.15	2	0.14 -0.16
10	40	0.19	2	0.16 -0.23
11	130	0.73	2	0.72 -0.75
12	120	0.33	2	0.30 -0.36
13	100	0.10	2	0.093-0.11
14	81	0.31	2	0.20 -0.43
15	18	1.02	2	0.77 -1.27
16	40	0.26	2	0.11 -0.42
17	163	0.060	2	0.043-0.078
18	157	0.063	2	0.046-0.080
19	137	0.10	2	0.079-0.14
20	69	0.13	2	0.037-0.24
21	20	0.31	2	0.28 -0.35
22	40	0.38	2	0.30 -0.47
23	201	0.72	2	0.66 -0.79
24	210	0.68	2	0.67 -0.69
25	200	0.46	2	0.41 -0.51
26	206	0.24	2	0.14 -0.35
27	76	0.25	2	0.23 -0.28
28	60	0.74	1	0.74
29	170	0.35	2	0.32 -0.39
30	242	1.18	2	1.16 -1.21
31	250	1.00	2	1.06 -0.94
32	250	1.05	2	1.05 -1.06
33	122	0.44	2	0.42 -0.46
34	14	0.35	1	0.35
35	202	0.41	2	0.41
36	194	0.63	2	0.47 -0.80
37	20	0.27	2	0.26 -0.29
38	25	0.13	2	0.12 -0.14
39	224	0.19	2	0.19
40	140	0.44	2	0.41 -0.48
41	212	0.45	2	0.39 -0.52
42	226	0.79	2	0.73 -0.85
43	240	0.71	2	0.64 -0.79
44	160	0.74	2	0.70 -0.78
45	155	0.26	2	0.25 -0.27
46	256	1.18	2	1.10 -1.26

TABLE 41 (CONTINUED)

Station[c]	Depth[a] meters	(b) Hg µg/g$_b$ dry wt. $\bar{X}$	n	range
47	256	1.55	1	1.55
48	244	0.79	2	0.7€ -0.82
49	240	0.48	2	0.43 -0.53
50	188	0.13	2	0.13 -0.14
51	256	1.11	2	0.84 -1.38
52	256	1.25	2	1.09 -1.41
53	240	1.36	2	1.13 -1.59
54	248	0.73	2	0.72 -0.75
55	252	0.31	2	0.30 -0.32
56	200	1.13	2	1.03 -1.24
57	268	0.87	2	0.84 -0.91
58	266	0.34	2	0.20 -0.48
59	268	0.078	2	0.064-0.092
60	264	0.013	2	0.010-0.017
61	168	0.019	2	0.011-0.028
62	160	0.14	2	0.13 -0.16
63	280	0.39	2	0.33 -0.45
64	280	0.16	2	0.15 -0.17
65	288	0.064	2	0.059-0.070
66	280	0.050	2	0.048-0.052
67	268	0.010	2	0.007-0.013
68	232	0.005	2	0.003-0.007
69	100	0.025	2	0.021-0.030

[a]Depths not corrected for tidal differences

[b]Value for each sample is an average of duplicate or triplicate determinations

[c]Samples locations shown on Figure 39.

Soure: Thompson and McComas 1973.

TABLE 42

MERCURY CONTENT OF SEDIMENT CORES FROM THE SQUAMISH DELTA
(SAMPLED BY THOMPSON AND MCCOMAS 1972)

Station	Upper Core 0-10 cm Hg µg/g dry weight			Lower Core >10 cm Hg µg/g dry weight			Maximum Depth Sampled (cm)
	$\bar{X}$	n	range	$\bar{X}$	n	range	
A	4.42	9	2.58 - 6.04[a]	7.51	2	5.63 - 9.40	12
B	0.28	10	0.018 - 1.12	0.057	7	0.029 - 0.088	17
C	0.52	10	0.13 - 0.85	0.51	9	0.048 - 0.11	19
D	8.64	10	2.62 - 20.00[b]	4.70	15	0.083 - 12.10	25
E	1.12	10	0.67 - 1.59	1.84	9	0.59 - 4.32	19
West	0.014	10	0.006-0.037	0.052	7	0.039-0.064	17
Central	0.066	10	0.036-0.095	0.062	7	0.019-0.151	17
East	0.683	10	0.080-2.160	0.737	3	0.340-1.060	13
78HW-W[c,d]	0.49	6	0.23 - 0.86[e]	0.094	5	0.080-0.110	15
100HW-W[f]	0.066	7	0.042-0.113[g]	0.046	11	0.030-0.070	22
50LW-E	0.30	10	0.16 - 0.79	0.30	7	0.15 - 0.47	17
100LW-E	0.059	9	0.020-0.260[h]		-		9
150LW-E	0.327	9	0.033-0.970[h]		-		9
200LW-E	0.60	10	0.02 - 1.50	0.017	3	0.010-0.020	13

[a] Value for 7-8 cm section of core not determined

[b] Value of 20 ppm Hg reported at 5-6 cm of core

[c] Transect west to east across Mamquam Blind Channel. HW= high water mark; LW = Low water mark

[d] Mud

[e] Value for 2-6 cm section of core not determined

[f] Very coarse sand

[g] Value for 5-6, 7-8, 9-10 cm sections of core not determined

[h] Value for 9-10 cm section of core not determined

Sample locations shown on Figure 40 for first 8 stations listed
site map for transect not available

Source: Thompson and McComas 1973

TABLE 43

COMPARISON OF SEDIMENT MERCURY CONTENT AT
HOWE SOUND SITES SAMPLED MORE THAN ONCE

A. Core Samples (0-10 cm) Hg µg/g dry weight ($\bar{X}$)[1]

Station	Thompson and McComas 1973	Beak 1977
West	0.014	<0.050
Central	0.066[2]	0.11
A	4.42	2.5
C	0.52	0.78
D	8.64[3]	3.7
E	1.12	2.9

[1]Values less than detection limit not included in means

[2]Value for 7-8 cm section of core not determined

[3]Value of 20,000 ppb Hg reported at 5-6 cm of core

Sample locations shown on Figure ii.

B. Grab Samples Hg µg/g dry weight ($\bar{X}$)[1]

Station	Thompson and McComas 1973	Beak 1977
1	0.091	<0.050
4	0.17	0.870
8	0.11	0.100
9	0.15	<0.050
10	0.19	<0.050
13	0.10	<0.050
14	0.31	0.055
18	0.063	0.066
25	0.46	0.081
42	0.79	0.27
47	1.55	0.59
52	1.25	0.28
60	0.013	0.076

[1]Values less than detection limit not included in means
Sample locations shown on Figure 39.
Source: Thompson and McComas 1973
FMC 1978

TABLE 44

MERCURY CONCENTRATIONS IN SEDIMENT CORES (0-10 cm) FROM HOWE SOUND

Station	Hg µg/g Dry Weight		
	$\bar{X}$	n*	Range
A	2.5	2	1.6 -3.5
C	0.78	2	0.16 -1.6
D	3.7	2	1.6 -5.5
E	2.9	2	1.1 -4.9
Central	0.11	2	0.078-0.14
West	<0.050+	*	<0.050
M_1	1.5	2*	1.5 -1.5
1	0.050	-	<0.050
4	0.870	2	0.840-0.910
8	0.100+	2	0.079-0.120
9	<0.050	-	<0.050
10	<0.050	-	<0.050
13	<0.050	-	<0.050
14	0.055+	2	0.055-0.055
18	0.066+	2	0.058-0.072
25	0.081+	2	0.059-0.11
42	0.27	2	0.17 -0.42
47	0.59	2	0.34 -0.78
52	0.28	2	0.23 -0.34
60	0.076	2*	0.075-0.076
WA	0.46	2	0.12 -0.78
WB	0.43	2	0.12 -0.83
WC	0.14	1	0.10 -0.18
WD	0.25 +	2	0.21 -0.28
WE	0.054+	1	0.054

At all stations 2 samples taken and 2 subsamples of each analyzed.
*at stations west and M_1 2 samples taken at each station, no subsamples taken.
+values below detection limit not included in means
Sample sites shown in Figures 39, 40 and 42
Source: Beak, 1978

TABLE 45

MERCURY CONCENTRATION IN SEDIMENT CORES FROM HOWE SOUND AND GEORGIA STRAIT, JANUARY 1977

Station	Depth Sample (cm)	Total Hg Dry Wt. µg/g	Mean Hg Concentration µg/g
1	Grab	0.646	0.65
		0.654	
2	0- 3	2.57	
	9-12	2.39	2.09
2a	Grab	1.32	
3	0- 2	0.628	
	8-10	0.562	
	9-12	0.562	0.59
	0- 3	0.604	
4	0- 3	0.097	
	3- 6	0.098	0.12
	12-15	0.131	
	9-12	0.145	
5	0- 3	0.073	
	3- 6	0.074	
	12-15	0.244	0.18
	9-12	0.312	
6	3- 6	0.180	
	0- 3	0.174	
	9-12	0.353	0.26
	6- 9	0.344	
7	0- 3	0.193	
	6- 9	0.712	0.53
	3- 6	0.207	
	9-12	0.992	
8	3- 6	0.296	
	0- 3	0.233	
	9-12	0.359	
	6- 9	0.426	0.24
	93-96	0.062	
	90-93	0.046	
9	3- 6	0.053	
	0- 3	0.066	0.06
	9-12	0.064	
	6- 9	0.061	

Source: Willis, Cunliffe, Tait & Co. Ltd., 1977 as cited in Beak 1977, sample locations shown in Figures 39 and 42.

TABLE 46

MERCURY CONCENTRATION OF SEDIMENT CORES FROM HOWE SOUND

Station	Upper Core 0–10 cm Hg µg/g dry weight $\bar{X}$	n	range	Lower Core >10 cm Hg µg/g dry weight $\bar{X}$	n	range	Maximum Depth Sampled (cm)
1	0.841	6	0.585–1.060[a]	0.610	9	0.025–1.580[b]	26
2	1.023	7	0.630–1.530[c]	0.267	6	0.015–0.725	22
3	0.728	7	0.015–1.270[d]	0.035	10	0.015–0.115	29
4	0.140	5	0.085–0.250	0.097	3	0.075–0.140	16
5	0.309	5	0.150–0.515	0.390	5	0.350–0.480	20
6	1.425	10	0.420–1.930[e]	0.113	8	0.015–0.665	26
7	0.722	6	0.295–1.500[f]	0.880	1		12
8	7.132	4	5.690–8.810		–		4
9	0.275	1			–		4
10	0.352	5	0.335–0.375	0.241	7	0.115–0.360	24
11	0.243	5	0.050–0.720	0.062	5	0.045–0.090	20
12	0.060	5	0.050–0.075	0.137	9	0.050–0.085	28
13	0.209	5	0.165–0.245	0.121	14	0.085–0.225	38
14	0.170	5	0.150–0.195	0.263	6	0.140–0.340	22
15	0.658	5	0.200–1.030	0.311	5	0.210–0.500	20
16	0.053	5	0.040–0.060	0.060	1		12
17	0.053	5	0.050–0.060	0.057	4	0.045–0.070	18
18	0.084	5	0.065–0.100	0.155	1		12
19	0.099	5	0.070–0.140	0.094	5	0.075–0.125	20
20	0.188	5	0.110–0.465	0.407	3	0.165–0.795	16
21	0.194	5	0.110–0.335	0.390	4	0.165–0.930	18
22	0.733	5	0.165–1.100	0.385	6	0.110–0.730	22
23	0.156	5	0.100–0.280	0.102	11	0.080–0.140	32
Box Core from Watts Point	0.417	10	0.190–0.965	0.532	12	0.090–1.050	22

[a]Replicate samples taken at 6–8cm

[b]Replicate samples taken at 14–16cm

[c]Replicate samples taken at 6–8cm

[d]Replicate samples taken at 0–2, 2–4cm

[e]Replicate samples taken at 0–2, 2–4, 4–6, 6–8, 8–10cm

[f]Replicate samples taken at 8–10cm

Sample locations shown on Figure 41.

Source: Macdonald and Wong, 1977.

TABLE 47

MERCURY ANALYSIS OF SEDIMENT GRAB SAMPLES FROM HOWE SOUND

Sample Number	Station	Mercury µg/g (dry wt.)
1A	HV-2	0.120
1B	HV-2	0.140
2A	HV-3	0.170
2B	HV-3	0.140
3A	HV-4	0.130
3B	HV-4	0.140
4	H-1	0.060
5A	H-3	0.170
5B	H-3	0.130
6A	H-4	0.130
6B	H-4	0.150
7A	H-5	0.130
7B	H-5	0.120
8A	H-6	0.070
8B	H-6	0.070

Sample locations shown in Figure 41.

Source: Macdonald and Wong, 1977.

TABLE 48

MERCURY CONCENTRATION OF SEDIMENT CORES FROM HOWE SOUND

Station	Distance from FMC (km)	Upper Core[a] Hg µg/g dry wt. $\bar{X}$	n	range	Lower Core[a] Hg µg/g dry wt. $\bar{X}$	n	range
A. August 1970							
1	0.35	0.61	3	0.38 -0.87			
2	0.98	1.45	3	1.08 -1.84	0.75	1	
3	1.98	0.66	3	0.49 -0.97	0.31	1	
4	2.96	1.59	3	1.23 -1.80	0.45	1	
5	3.96	1.91	3	1.72 -2.22	0.25	1	
6	4.54	1.78	3	1.68 -1.98	0.45	1	
7	6.44	0.46	3	0.32 -0.98	0.39	1	
8	5.90	1.44	3	1.11 -1.65	0.08	1	
9	6.05	1.47	3	1.10 -1.66	0.13	1	
10	6.44	0.36	3	0.31 -0.41	0.05	2	0.03 -0.07
11	7.16	0.31	3	0.11 -0.43	0.16	2	0.14 -0.19
12	7.48	0.25	3	0.12 -0.36	0.22	2	0.15 -0.29
13	8.16	0.08	3	0.03 -0.15	0.06	3	<0.02 -0.06
B. September 1971							
1	0.21	4.57	3	3.11 -6.06	9.91	3	2.87 -14.36
2	0.21	9.14	3	3.66 -18.73	4.47	3	0.44 -7.34
3	0.21	1.15	3	0.70 -1.93	0.31	3	0.11 -0.63
4	1.21	0.13	3	0.04 -0.24	0.42	3	0.10 -0.82
5	1.21	0.03	3	0.01 -0.04	0.20	3	0.16 -0.25
6	1.21	0.03	3	0.03 -0.04	0.53	3	0.39 -0.62
7	0.80	0.39	3	0.16 -0.67	0.68	3	0.13 -1.05
8	0.80	0.06	3	0.05 -0.07	0.02	3	0.01 -0.02
9	0.80	0.03	3	0.03 -0.04	0.02	3	0.01 -0.04
Christie Islet		0.04	3	0.02 -0.05	0.04	3	0.02 -0.05
Stawamus Delta		1.96 [b]	3	1.71 -2.14	0.63 [b]	3	0.30 -1.21
Squamish Delta		0.01	1		0.01	2	0.01 -0.01

[a] Depth of cores not specified

[b] Values below detection limit not included in mean

Sample locations shown on Figure 41.

Source: Beak, 1978

TABLE 49

MERCURY LEVELS IN SEDIMENTS NEAR SQUAMISH TERMINALS AND FMC CHEMICALS, SQUAMISH, B.C., JUNE 1980 (µg/g). (DRY WEIGHT)

STATION/DEPTH +	COMPOSITE*	0-10 CM **	10-20 CM **	20-30 CM **
STN. 1 CORE 1	(1.20)	0.55	0.11	-
2		0.55	0.93	-
3		0.67	1.15	-
STN. 2 CORE 1	(17.0)	8.10	7.90	5.10
2		17.90	6.80	10.10
3		9.00	5.90	14.70
STN. 3 CORE 1	(22.5)	3.23	3.73	13.30
2		2.75	3.44	33.2
3		2.82	4.70	15.5
STN. 4 CORE 1	(2.95)	0.61	0.34	< 0.05
2		0.72	0.79	0.14
3		0.43	0.36	< 0.05
STN. 5 CORE 1	(2.16)	1.20	1.88	-
2		1.22	2.48	-
3		1.07	1.52	-
STN. 6 CORE 1	(0.220)	0.14	0.07	-
2		0.23	0.12	-
3		0.15	0.13	-
STN. 7 CORE 1	(2.07)	2.23	2.40	-
2		2.26	2.33	-
3		1.96	1.87	-
STN. 8 CORE 1	(1.92)	2.01	1.45	-
2		2.07	1.56	-
3		1.95	1.27	-
STN. 9 CORE 1	(1.89)	2.40	16.80	8.24
2		1.88	1.81	-
3		2.49	4.88	-
STN.10 CORE 1	(0.288)	0.24	0.25	-
2		0.24	0.32	-
3		0.27	0.28	-

*Composite sample analysed by Environmental Protection Service - Fisheries and Oceans Laboratory, West Vancouver

** Core Samples analysed by Ministry of Environment, Environmental Laboratory Victoria, B. C.

+ For station locations see Figure 35

TABLE 49 B

MERCURY LEVELS IN SEDIMENTS AND IN SEEPAGE SAMPLES NEAR FMC CHEMICALS[1]

Station[2]	Date	Mercury Concentration		
		Sediments (µg/g)	Seepage (µ g/L)	
1	July, 1978	0.39		
	March, 1979	0.36		
2	July, 1978	0.27		
	March, 1979	0.15		
3	July, 1978	0.21	Dissolved	Total
4	March, 1979	18	650	750
	June, 1979	3.15	3.2	10.6
5	March, 1979	8.0	110	220
	June, 1979	2.81		4
CONTROL	March, 1979	0.11	0.07	0.40

(1) Source: B.C. Ministry of Environment, Waste Management Branch Regional Office, Surrey

(2) Station locations indicated in Figure 17

TABLE 50

MONITORING DATA REQUIRED UNDER OCEAN DUMPING

CONTROL ACT PERMITS - MERCURY

Permit		Site	Date	Values ug/g dry wt.
MacMillan Bloedel [1]	0816	Station 1(4517) [a]	Feb 20 1980	0.07
		Station 2(4731) [a]	Feb 28 1980	0.15
	0631	Stawamus R. [b]	Feb 27 1979	0.68
				0.37
	0417	Foreshore lot #7139 [b]	Feb 21 1978	1.20
				0.08
	0233	Foreshore lot #7139 [c]	Feb 23 1977	1.08
		Mamquam Blind Channel [2]	March 1976	1.0-3.0
Weldwood [1]	0594	Sawdust Scow Berth [d] #2	Feb 19 1979	0.12
		Lumber Dock #2	Feb 14 1979	0.25
		Hog Scow Berth #2	Feb 12 1979	<0.01
		Sawdust Scow Berth #1	Feb 13 1979	0.44
		Lumber Dock #1	Feb 14 1979	0.25
		Log Haul #2	Feb 11 1979	<0.01
		Log Haul #1	Feb 10 1979	<0.01
		Hog Scow Berth #1	Feb 12 1979	0.02
	0012	Log Haul	March 1 1976	0.24
		#2 Top	March 1 1976	1.32
		#2 Bottom	March 1 1976	4.94
		Mamquam Channel West [3] 0-1 ft		0.02
		6-9 ft		0.02
		9-13 ft		0.02
		Central 0-1 ft		0.03
		6-10 ft		0.02
		10-12 ft		0.03
		East 0-1 ft		0.05
		7-10 ft		0.08
		10-13 ft		0.02
		Unspecified landfill: [2] top		0.71
		bottom		1.1
		Unspecified dredge spoil [2]		1.08
		Mamquam Channel Dredge Spoil [4]	1977	0.10-0.99 x̄0.56; n=6

Source:

1 Department of Environment, Environmental Protection Service, Ocean Dumping Section, ODCA permit files. Unpublished data.

a MacMillan Bloedel Limited, Analysis by CanTest Ltd. (files 4517D,4731D) 1980

b MacMillan Bloedel Limited, Analysis by CanTest Ltd. (file 9390-C) 1979

c MacMillan Bloedel Limited, Analysis by B.C.Research (file 1-05-739(14)) 1977

d Weldwood Canada, Analysis by B.C.Research (file 1-05-739(32)) 1979

2 Department of Environment, Environmental Protection Service, Unpublished data.

3 Department of Public Works, Unpublished data, prepared by B.C.Research.

4 B.C. Research, Unpublished data (file 1-05-739(17)) 1977

TABLE 51

MONITORING DATA REQUIRED UNDER OCEAN DUMPING

CONTROL ACT PERMITS - CADMIUM

Permit		Site	Date	Values ug/g dry wt.
MacMillan Bloedel	0816	Sample 1(4517)	Feb 20 1980	< 0.5
		Sample 2(4731)	Feb 28 1980	< 0.5

Source:

Department of Environment, Environmental Protection Service, Ocean Dumping Section, O.D.C.A. permit files. Unpublished data.
MacMillan Bloedel Limited, Analysis by CanTest Ltd. (files 4517D , 4731D)1980

TABLE 52

POLYCHLORINATED BIPHENYLS (PCB's) IN ROAD SEDIMENTS IN SQUAMISH[1]

Site description	Number of Samples	Contaminant	Concentration (µg/g)
Alley in Squamish	2	Arochlor 1254	1.0 0.39
Logging Rd., Cheekeye area	1	Arochlor 1260	0.030

Sampled October 11, 1978

[1] Source: Environment Canada, Environmental Protection Service. Unpublished data.

TABLE 53

MONITORING DATA REQUIRED UNDER OCEAN DUMPING CONTROL ACT PERMITS - PCB's

Permit		Site	Date	Values ug/g dry wt.
MacMillan Bloedel	0816	Station 1(4517)	Feb 20 1980	trace
		Station 2(4731)	Feb 28 1980	0.005
	0816	[b] Stawamus R.	Feb 27 1979	<0.005
	0417	[b] Foreshore lot #7139	Feb 21 1978	9.0)Arochlor 5.0) 1260
Weldwood	0594	[c] Sawdust Scow Berth #2	Feb 19 1979	<0.02
		Lumber Dock #2	Feb 14 1979	0.03
		Hog Scow Berth #2	Feb 12 1979	<0.02
		Sawdust Scow Berth #1	Feb 13 1979	0.02
		Lumber Dock #1	Feb 14 1979	0.05
		Log Haul Apron #2	Feb 11 1979	0.05
		Log Haul Apron #1	Feb 10 1979	0.03
		Hog Scow Berth #1	Feb 12 1979	0.04

Source:

Department of Environment, Environmental Protection Service, Ocean Dumping Section O.D.C.A. permit files. Unpublished data.

a MacMillan Bloedel Limited, Analysis by CanTest Ltd. (files 4517D,4731D) 1980

b MacMillan Bloedel Limited, Analysis by CanTest Ltd. (files 9390-C 1979
4700-C 1978)

c Weldwood Canada. Analysis by B.C.Research (file 1-05-739(32)) 1979.

TABLE 54

CHLOROPHENOL, CHLOROBENZENE, CHLOROANISOLE CONCENTRATION IN SEDIMENTS[1]

Site Description	Number of Samples	Contaminant	Concentration[2] (µg/kg dry weight)
Weldwood (Mamquam Channel)	10	pentachlorophenol	52.8
	10	tetrachlorophenol	98.7
	10	trichlorophenol	52.1
	10	hexachlorobenzene	ND
	10	pentachlorobenzene	ND
	10	tetrachlorobenzene	ND
	10	pentachloroanisole	ND

Sampled November 27, 1978

[1] Source: Monitoring environmental contamination from chlorophenol contaminated wates generated in the wood preservation industry. DOE, EPS Pacific and Yukon Region, Regional Program Report 79-24 prepared by Can Test Ltd., and E.V.S. Consultants Ltd., April 1979.

[2] Limits of quantitation: chlorophenols 5µg/kg; chlorobenzenes 0.5 µg/kg; pentachloroanisole 0.5 µg/kg.

ND - not detected (approximately ¼ of limit of quantitation)

TABLE 55

CHLOROBENZENES IN CHLOR-ALKALI INDUSTRIES FMC Ltd (Squamish)

SAMPLE DESCRIPTION AND LOCATION				CHLOROBENZENES (PPM)		LOADING[2]
Media	Sample description (ref. Figure 46)	Survey[1] No.	Station[3] No.	Hexa-	Penta-	Kg/Year
Effluent	grab sample from inlet to effluent pond	1	1	$5x10^{-5}$ (50PPT)		
	3 1/2 hr. individual samples - 1045 hrs.	2	1	$2.7x10^{-5}$ (27 PPT)		
	- 1115 hrs.	2	1	$2x10^{-5}$ (20 PPT)		
	- 1145 hrs.	2	1	$4.8x10^{-5}$ (48 PPT)		
	- 1215 hrs.	2	1	$1x10^{-5}$ (10 PPT)		
	- 1245 hrs.	2	1	$9.5x10^{-5}$ (95 PPT)		
	- 1315 hrs.	2	1	$5.2x10^{-5}$ (52 PPT)		
	- 1345 hrs.	2	1	$2.0x10^{-5}$ (20 PPT)		
	- 1415 hrs.	2	1	$1.1x10^{-5}$ (11 PPT)		
	3 1/2 hr. composite	2	1	$1.4x10^{-5}$ (14 PPT)		0.18
	mean concentration	2	1	$3.5x10^{-5}$ (35 PPT)		0.45
	grab sample from outlet from effluent pond	1	2	$11x10^{-5}$ (110 PPT)		
	grab sample from pond discharge to sea	1	3	$4x10^{-5}$ (40 PPT)		
	grab sample from pond discharge to sea	1	3	$1.9x10^{-5}$ (19 PPT)		
Sediment	near inlet to effluent pond	1	4	19.000		
	near outlet from effluent pond	1	5	5.600		
	near pond discharge to sea	1	6	0.250		
	near pond discharge to sea	2	6	0.870	0.057	
	near plant at high tide line	1	8	< 0.001		
	near plant at high tide line	1	9	< 0.001		
	near plant at very low tide	2	10	0.005		
	near plant at very low tide	2	11	0.005		
Soil	from sludge disposal area	1	7	0.005		

1 Survey No. 1 was conducted in September 1977, Survey No. 2 in August 1978.
2 Calculated from a flow of 7.8 MIG PD.
3 See Figure 37

Source: Department of Environment, Environmental Protection Service, Unpublished.

TABLE 56

ANALYSES OF SEDIMENTS COLLECTED SEPTEMBER 24, 1980

AIR AND WATER QUALITY WORK GROUP

Sample Location	Pentachlorophenol µg/g (Dry)	Tetrachlorophenol µg/g (Dry)
1	0.0043	0.0055
2	0.029	0.037
3	0.0083	0.010
4	0.0083	0.010
5	0.0035	0.016
6	0.012	<0.005
7	0.0088	0.0093
8	0.018	0.012
9	0.0079	0.0054
10	0.0076	0.0052
11	0.74	0.52
12	0.19	0.071
13	0.027	0.010

Note: All sediments 0-10 cm.
Sampling stations indicated in Figure 38
Detection Limits: pentachlorophenol - 0.002 ug/g
tetrachlorophenol - 0.005 ug/g

TABLE 57

SCHEDULE I

OCEAN DUMPING CONTROL ACT

Substances prohibited from being dumped when at concentrations exceeding those specified below:

a) Organohalogen compounds, quantities shall not exceed 0.01 parts of a concentration shown to be toxic to marine animal and plant sensitive organisms in a bioassay sample and test carried out in accordance with procedures established or approved by the Minister;

b) Mercury and mercury compounds in a solid phase of a waste, 0.75 milligrams per kilogram, and in the liquid phase of a waste, 1.5 milligrams per kilogram;

c) Cadmium and cadmium compounds in a solid phase of a waste, 0.6 milligrams per kilogram and in the liquid phase of a waste, 3.0 milligrams per kilogram;

d) Persistent plastics and other persistent synthetic materials, four percent by volume, in a suitably comminuted form;

e) crude oil, fuel oil, heavy diesel oil and lubricating oils, hydraulic fluids and any mixtures containing any of them, any quantity that yields more than 10.0 milligrams per kilogram of n-hexane soluble substances;

f) high level radioactive wastes or other high level radioactive matter that may be prescribed;

g) substances in whatever form produced for biological and chemical warfare.

TABLE 58

SCHEDULE II

OCEAN DUMPING CONTROL ACT

The following substances are restricted:

a) arsenic and its compounds;
b) lead and its compounds;
c) copper and its compounds;
d) zinc and its compounds;
e) organosilicon and its compounds;
f) cyanides;
g) fluorides;
h) pesticides and their by-products not included in Schedule I;
i) beryllium and its compounds;
j) chromium and its compounds;
k) nickel and its compounds;
l) vanadium and its compounds;
m) containers and scrap metal;
n) radioactive wastes or other radioactive matter not included in Schedule I;
o) substances that by reason of their bulk would interfere with fishing.

TABLE 59

MERCURY CONCENTRATIONS IN AQUATIC INVERTEBRATES OF HOWE SOUND

LOCATION Description	SPECIES	DATE	NO. OF SAMPLES	Hg CONCENTRATION (ppm Wet Weight)		Ref
				Mean ± S.D.	Range	
Howe Sound (B.C. Area 28)	Coon Striped Shrimp	1971	1	0.45		7
	Shrimp	1971	1	0.25		7
	Prawn	1971	5	0.50 ± 0.16	0.32-0.63	7
	Prawn	1971	-	0.20		7
	Dungeness Crab	1971	41	1.25 ± 0.65	0.43-2.62	7
Howe Sound Zone 1	Dungeness Crab	1970	14	5.52 ± 5.19	1.52-13.40	5
	Dungeness Crab	1971	20	1.89 ± 0.74	0.79-3.39	5
	Dungeness Crab	1972	9	2.14 ± 1.00	0.77-3.29	5
	Dungeness Crab	1973	9	0.92 ± 0.74	0.15-2.31	5
	Dungeness Crab	1974	10	0.36 ± 0.19	0.15-0.77	5
	Dungeness Crab	1975	20	0.20 ± 0.18	0.06-0.88	5
	Dungeness Crab	1977	10	0.28 ± 0.10	0.15-0.42	4
	Blue Mussel	1975	2	0.41 ± 0.04	0.13-0.70	5
	Basket Cockle	1975	1	0.03		5
	Prawn	1977	10	0.11 ± 0.07	0.03-0.20	4
- adjacent to FMC chlor-alkali Plant Squamish	Dungeness Crab	1970	10	1.77 ± 0.83	0.84-3.20	2
	Dungeness Crab	1971	3	1.01 ± 0.18	0.81-1.17	2
	Dungeness Crab	1972	10	1.06 ± 0.38	0.76-1.72	2
	Dungeness Crab	1973	9	1.16 ± 0.42	0.59-1.92	2
	Dungeness Crab	1974	10	0.68 ± 0.31	0.33-1.28	2
	Dungeness Crab	1975	10	0.27 ± 0.15	L0.05-0.58	2
	Dungeness Crab	1976	15	0.18 ± 0.07	0.08-0.36	2
	Dungeness Crab	1977	14	0.21 ± 0.03	0.07-0.53	2
Zone 2	Dungeness Crab	1970	7	2.70 ± 2.04	1.47-7.22	6
	Dungeness Crab	1975	6	0.15 ± 0.06	0.07-0.24	6
	Dungeness Crab	1977	10	0.30 ± 0.08	0.14-0.39	4
	Shrimp	1970	1	2.75		6
	Prawn	1977	10	0.18 ± 0.08	0.07-0.27	4

TABLE 59 (CONTINUED)

MERCURY CONCENTRATIONS IN AQUATIC INVERTEBRATES OF BRITISH COLUMBIA

LOCATION Description	SPECIES	DATE	NO. OF SAMPLES	Hg CONCENTRATION (ppm Wet Weight)		Ref
				Mean ± S.D.	Range	
- Shannon Area	Dungeness Crab	1970	1	3.20		
	Dungeness Crab	1971	4	0.90 ± 0.61	0.39-1.74	2
	Dungeness Crab	1972	10	1.02 ± 0.44	0.57-1.91	2
	Dungeness Crab	1973	10	0.96 ± 0.63	0.13-2.51	2
	Dungeness Crab	1974	10	0.42 ± 0.25	0.13-0.85	2
	Dungeness Crab	1975	10	0.08 ± 0.05	L0.05-0.22	2
	Dungeness Crab	1976	15	0.19 ± 0.07	0.10-0.31	2
	Dungeness Crab	1977	15	0.14 ± 0.07	L0.05-0.24	3
	Barnacle	1974	-	0.07		
Howe Sound Zone 3	Dungeness Crab	1970	3	0.74 ± 0.85	0.22-1.72	5
	Dungeness Crab	1971	4	1.89 ± 1.01	0.44-2.62	5
	Dungeness Crab	1973	2	0.94 ± 0.65	0.48-1.40	5
	Dungeness Crab	1974	7	0.23 ± 0.16	0.08-0.55	5
	Dungeness Crab	1975	5	0.09 ± 0.05	0.04-0.18	5
	Dungeness Crab	1977	10	0.16 ± 0.10	0.04-0.35	4
	Red Crab	1973	3	0.16 ± 0.06	0.11-0.23	5
	Red Crab	1974	1	0.29		
	Red Crab	1975	1	0.12		
	Prawn	1977	3	0.08 ± 0.06	0.07-0.14	4
- Watts Point (north)	Dungeness Crab	1970	4	1.09 ± 0.78	0.30-1.80	2
	Dungeness Crab	1971	10	0.70 ± 0.39	0.18-1.48	2
	Dungeness Crab	1972	10	0.58 ± 0.41	0.27-1.30	2
	Dungeness Crab	1973	10	0.48 ± 0.29	0.11-0.95	2
	Dungeness Crab	1974	10	0.54 ± 0.36	0.15-1.22	2
	Dungeness Crab	1975	10	0.11 ± 0.09	L0.05-0.33	2
	Dungeness Crab	1976	15	0.16 ± 0.11	L0.05-0.38	2
	Dungeness Crab	1977	15	0.16 ± 0.07	L0.05-0.27	5
Zone 4	Mussel	1975	10	0.02 ± 0.01	0.02-0.03	5
	Dungeness Crab	1977	10	0.12 ± 0.06	0.05-0.24	4
- Britannia Beach	Barnacle	1974	-	0.05		3

TABLE 59B

MERCURY CONCENTRATIONS IN FISH FROM HOWE SOUND

LOCATION Description	SPECIES	TISSUE	DATE	NO. OF SAMPLES	Hg CONCENTRATION (ppm Wet Weight)		Ref
					Mean ± S.D.	Range	
B.C. Area 28	Lingcod	muscle	1971	1	0.42		7
	Brown Rockfish	muscle	1971	2	0.54 ± 0.16	0.42-0.65	7
	Yelloweye Rockfish	muscle	1971	2	1.16 ± 0.08	1.10-1.21	7
	Rockfish	muscle	1971	2	0.98 ± 0.03	0.96-1.00	7
	Flounder	muscle	1971	1	0.15		7
	Spiny Dogfish	muscle	1971	10	1.43 ± 0.63	0.75-2.23	7
Howe Sound (B.C. Area 28) Zone 1	Rockfish	muscle	1970	1	0.95		1
	Sculpin	muscle	1970	5	1.41 ± 0.20	1.14-1.62	5
	Spiny Dogfish	muscle	1970	5	0.49 ± 0.49	0.05-1.25	5
	Spiny Dogfish	muscle	1970	9	1.40 ± 0.47	0.75-2.01	5
	Northern Anchovy	muscle	1970	2	0.32 ± 0.06	0.28-0.36	5
	Pacific Herring	muscle	1970	3	0.24 ± 0.09	0.14-0.28	5
	Chinook Salmon	muscle	1977	1	0.06		4
	Chum Salmon Fry	muscle	1970	1	0.01		5
	Staghorn Sculpin	muscle	1973	5	0.28 ± 0.10	0.20-0.43	5
	Starry Flounder	muscle	1970	1	2.40		5
	Flounder	muscle	1970	4	0.18 ± 0.08	0.10-0.28	5
	Pacific Cod	muscle	1973	1	L0.01		5
	Spiny Dogfish	muscle	1972	3	2.09 ± 0.72	1.53-2.90	5
	Spiny Dogfish	muscle	1973	10	2.07 ± 0.79	0.29-2.92	5
	Spiny Dogfish	muscle	1977	10	1.06 ± 0.38	0.44-1.5	4
	Pacific Herring	muscle	1977	1	0.02		4
	Dolly Varden	muscle	1970	3	0.15 ± 0.21	0.03-0.40	5
	Chinook Salmon	muscle	1970	6	0.26 ± 0.03	0.24-0.31	5
	Chum Salmon Fry	muscle	1971	1	0.13		4
	Pink Salmon Fry	muscle	1970	1	0.09		5
	Salmonid Smolt	muscle	1971	1	0.14		5
	Steelhead Trout	muscle	1970	5	0.05 ± 0.04	0.01-0.08	5
	Surf Smelt	muscle	1977	1	0.04		4

TABLE 59B (CONTINUED)

MERCURY CONCENTRATIONS IN FISH FROM HOWE SOUND

LOCATION Description	SPECIES	TISSUE	DATE	NO. OF SAMPLES	Hg CONCENTRATION (ppm Wet Weight)		Ref
					Mean ± S.D.	Range	
Zone 1 - 2	Quillback Rockfish	muscle	1978	18	0.95 ± 0.64	0.18-2.20	1
Zone 2	Rockfish	muscle	1970	1	1.44		5
	Lingcod	muscle	1970	3	2.11		5
	Flounder	muscle	1970	3	1.28 ± 0.24	1.00-1.42	5
	Rex Sole	muscle	1977	1	0.09		4
	Flathead Sole	muscle	1978	3	0.33 ± 0.21	0.20-0.58	4
	Rock Sole	muscle	1977	3	0.04 ± 0.01	0.03-0.05	4
	Slender Sole	muscle	1977	2	0.78 ± 0.14	0.68-0.88	4
	Dover Sole	muscle	1977	1	0.11		4
	English Sole	muscle	1977	11	0.03 ± 0.02	0.02-0.06	4
	Spiny Dogfish	muscle	1970	1	1.00		5
	Spiny Dogfish	muscle	1977	10	0.67 ± 0.46	0.28-1.90	4
Zone 3	Rockfish	muscle	1970	1	1.04		5
	Rockfish	muscle	1971	2	0.77 ± 0.27	0.58-0.96	5
	Rockfish	muscle	1973	1	0.48		5
	Spiny Dogfish	muscle	1977	10	0.66 ± 0.31	0.23-1.20	4
	Ratfish	muscle	1977	3	0.38 ± 0.22	0.13-0.57	4
	Lingcod	muscle	1970	1	1.59		5
	Lingcod	muscle	1978	5	0.42 ± 0.27	0.10-0.68	4
	Quillback Rockfish	muscle	1978	5	0.41 ± 0.36	0.15-0.99	4
	Striped Seaperch	muscle	1973	2	0.41 ± 0.03	0.39-0.43	5
	Walleye Pollock	muscle	1977	1	0.79		4
	English Sole	muscle	1977	11	0.13 ± 0.07	0.05-0.29	4
	Rex Sole	muscle	1977	3	0.53 ± 0.36	0.11-0.75	4
	Rock Sole	muscle	1977	1	0.04		4

TABLE 59B (CONTINUED)

MERCURY CONCENTRATIONS IN FISH FROM HOWE SOUND

LOCATION Description	SPECIES	TISSUE	DATE	NO. OF SAMPLES	Hg CONCENTRATION (ppm Wet Weight)		Ref
					Mean ± S.D.	Range	
Zone 3 (cont'd)	Slender Sole	muscle	1977	3	0.37 ± 0.19	0.22-0.59	4
	Dover Sole	muscle	1978	2	0.05 ± 0.01	0.04-0.05	4
	Spring Salmon	muscle	1970	3	0.37		5
	Salmon Smolt	muscle	1970	3	0.28		5
	Chum Salmon Fry	muscle	1971	1	0.05		5
Zone 4	Spiny Dogfish	muscle	1977	10	0.97 ± 0.49	0.26-1.6	4
	Copper Rockfish	muscle	1975	5	0.57 ± 0.22	0.33-0.88	5
	Copper Rockfish	muscle	1978	1	0.23		4
	Quillback Rockfish	muscle	1975	2	0.32 ± 0.12	0.24-0.41	4
	Quillback Rockfish	muscle	1978	4	0.47 ± 0.36	1.21-1.0	4
	Quillback Rockfish	muscle	1978	15	0.48 ± 0.35	0.13-1.3	1
	Striped Seaperch	muscle	1975	4	0.15 ± 0.08	0.07-0.26	5
	Lingcod	muscle	1975	2	0.39 ± 0.31	0.17-0.61	5
	Lingcod	muscle	1978	3	0.16 ± 0.09	0.10-0.27	4
	Kelp Greenling	muscle	1978	1	0.59		4
	Slender Sole	muscle	1978	5	0.42 ± 0.18	0.19-0.67	4

Source: Taken from Garrett, C. In prep. Mercury Contamination in the BC and Yukon Environments. E.P.S. Draft Report.

References as cited in Garrett.

1. Beak Consultants Ltd., Unpublished data.
2. Beak Consultants Ltd. 1978
3. BC Pollution Control Branch, Lower Mainland, Unpublished data.
4. Harbo, R.M. and I.K. Birtwell.
5. Harbo, R.M. and I.K. Birtwell.
6. Medical Services Branch. Unpublished data.
7. Vancouver Fish Inspection Laboratory, Department of Fisheries and Environment. Unpublished data.

TABLE 60

SELECTED TRACE METAL DATA FOR CRUSTACEANS AND FISH FROM HOWE SOUND, B.C., MAY 1977-APRIL 1978[1]

Zone	Species	No.	Trace Metal (µg/gm)					
			Hg (wet) Mean (SD) Range	Hg (dry) Mean (SD) Range	Cu (dry) Mean (SD) Range	Pb (dry) Mean (SD) Range	Zn (dry) Mean (SD) Range	Cd (dry) Mean (SD) Range
1	Cancer magister	(10)	0.278(.096) .15-.42	1.399(.51) .75-2.2	55.5(16.06) 31-83	4.86(.096) 4.7-5	204.2(21.24) 176-241	.486(.01) .47-.5
	Pandalus platyceros	(10)	0.159(.166) .025-.2	.536(.323) .11-.97	38.02(18.76) 21.6-87.5	5.26(.692) 4.8-6.6	55.92(9.89) 49.7-83.4	.526(.069) .48-.66
	Squalus acanthias	(10)	1.059(.385) .44-1.5	4.32(1.39) 1.6-5.8	6.53(3.92) 2.53-16.6	4.74(.097) 4.6-4.9	10.81(2.06) 7.9-14.9	.474(.01) .46-.49
	Clupea harengus pallasi	(1)	0.024	0.079	1.80	<4.90	11.50	<0.49
	Oncorhychus tshawytscha	(1)	0.064	0.310	2.00	<4.70	22.60	<0.47
	Hypomesus pretiosus	(1)	0.037	0.150	5.90	<5.70	71.40	<0.57
2	Cancer magister	(10)	.299(.085) .14-.39	1.612(.503) .72-2.2	57.59(15.32) 40.2-92.0	4.9(.105) 4.7-5	215.9(25.87) 175-253	.489(.01) .47-.5
	Pandalus platyceros	(10)	.178(.075) .07-.27	.759(.352) .31-1.4	28.31(4.9) 23.6-33.9	4.85(.172) 4.8-5	49.4(6.9) 36.7-59	.486(.018) .48-.5
	Squalus acanthias	(10)	.672(.458) .28-1.9	2.79(1.85) 1.3-7.7	6.278(5.06) .98-17.5	4.82(.116) 4.7-5	11.89(2.86) 6.5-17.7	.482(.011) .47-.5
	Glyptocepalus zachirus	(1)	0.087	0.461	<1.3	<6.5	13.90	<0.65
	Hippoglossoides elassodon	(3)	.33(.214) .2-.58	1.87(1.25) 1-3.3	2.37(.462) 2.1-2.9	12.3(2.31) 11-16	16.94(1.16) 15.7-18	1.23(.23) 1.1-1.5
	Lepidopsetta bilineata	(3)	.04(.008) .031-.046	.087(.048) .133-.221	1.33(.25) 1.1-1.6	6.56(1.1) 5.7-7.8	19.07(2.87) 17-22.3	.657(.11) .57-.78
	Lyopsetta exilis	(2)	.777(.14) .678-.876	4.13(.622) 3.69-4.57	3.9(.99) 3.2-4.6	19.5(4.95) 16-23	21.25(6.15) 16.9-25.6	1.95(.495) 1.6-2.3

TABLE 60 (CONTINUED)

Zone	Species	No.	Trace Metal (µg/gm)					
			Hg (wet) Mean (SD) Range	Hg (dry) Mean (SD) Range	Cu (dry) Mean (SD) Range	Pb (dry) Mean (SD) Range	Zn (dry) Mean (SD) Range	Cd (dry) Mean (SD) Range
	Microstomus pacificus	(1)	0.105	0.544	<0.98	<4.90	15.30	<0.49
	Parophrys vetulus	(11)	.033(.015) .017-.062	.147(.068) .081-.315	2.2(3.18) .94-11.7	5.61(1.41) 4.6-9.5	19(3.37) 15.2-24.7	.561(.141) .47-.95
3	Cancer magister	(10)	0.161(.104) .035-.35	.785(.526) .31-1.8	49.52(12.93) 30.2-68	4.86(.237) 4.2-5	209.2(45.02) 166-306	.486(.024) .42-.5
	Pandalus platyceros	(2)	.075(.063) .015-.14	.344(.284) .063-.63	19.65(1.48) 18.6-20.7	<4.90	54.65(6.01) 50.4-58.9	<0.49
	Squalus acanthias	(10)	.66(.31) .23-1.2	2.61(1.34) .85-4.9	12.35(16.06) 2.1-55.9	4.79(.137) 4.6-5	11.06(2.61) 6.8-16.2	.479(.014) .46-.5
	Hydrolagus colliei	(3)	.385(.225) .134-.568	1.841(1.07) .613-2.570	1.9(.4) 1.4-2.1	4.87(.23) 4.6-5	17.53(3.99) 14.70-22.10	.497(.023) .46-.5
	Theragra chalcogramma	(1)	0.149	0.792	6.30	<5.30	26.40	<0.53
	Sebastes maliger	(5)	.41(.36) .178-.992	1.94(1.78) .699-4.85	4.25(4.33) .94-11.8	4.82(.084) 4.7-4.9	14.44(1.63) 12.7-16.7	.482(.008) .47-.49
	Ophiodon elongatus	(5)	.415(.27) .103-.677	1.96(1.28) .47-3.17	5.22(2.9) 2.9-10.2	4.7(.07) 4.6-4.8	32.66(11.48) 18.8-45.8	.47(.007) .46-.48
	Glyptocephalus zachirus	(2)	.528(.366) .106-.749	2.95(2.12)	1.85(1.21) .99-2.70	8.95(5.73) 4.90-13.00	14.45(.07) 14.4-14.5	.895(.573) .49-1.30
	Lepidopsetta bilineata	(1)	0.041	0.180	12.40	<5.00	18.20	<0.50
	Lyopsetta exilis	(3)	.397(.186) .219-.590	2.09(0.91) 1.13-2.94	5.27(3.94) 1.7-9.5	26.43(20.07) 8.3-48	9(2.88) 5.9-11.6	2.64(2.01) .83-4.8

TABLE 60 (CONTINUED)

Zone	Species	No.	Trace Metal (µg/gm)					
			Hg (wet) Mean (SD) Range	Hg (dry) Mean (SD) Range	Cu (dry) Mean (SD) Range	Pb (dry) Mean (SD) Range	Zn (dry) Mean (SD) Range	Cd (dry) Mean (SD) Range
	Microstomus pacificus	(2)	.045(.008) .039-.05	.26(.05) .22-.29	2.75(2.05) 1.3-4.4	13.65(10.30) 6.3-21	20.75(7.28) 15.6-25.9	1.37(1.04) .63-2.1
	Parophrys vetulus	(10)	.13(.07) .053-.29	.726(.376) .305-1.62	3.13(3.13) .98-11	4.98(.282) 4.8-5	19.29(2.07) 16.2-22.5	.498(.028) .48-.58
4	*Cancer magister*	(10)	.116(.06) .048-.24	.61(.32) .32-1.3	34.42(8.38) 21.5-49.6	4.86(.13) 4.6-5	224.8(29.65) 176-253	.486(.01) .47-5
	Squalus acanthias	(10)	.97(.49) .26-1.6	3.7(1.87) 1-6	7.81(8.48) .93-28	4.79(.11) 4.7-4.9	11.85(2.95) 9.2-19.1	.479(.01) .47-.49
	Sebastes caurinus	(1)	0.228	1.050	10.60	<4.60	16.30	<0.46
	Sebastes magliger	(4)	.45(.36) .3-1	2.17(1.77) 1-4.83	1.5(.56) 1-2.3	4.9(.12) 4.8-5	16.68(1.02) 15.4-17.8	.49(.01) .48-.5
	Hexagrammos decagrammus	(1)	0.590	2.880	3.70	<4.90	16.60	<0.49
	Ophiodon elongatus	(3)	.16(.09) .104-.271	.746(.42) .465-1.230	3.8(4.16) 1.2-8.6	4.83(.06) 4.8-4.9	30.33(5.62) 26.6-36.8	.483(.06) .48-.49
	Lyopsetta exilis	(5)	.42(.18) .19-.67	2.32(.94) .91-3.5	4.32(1.94) 1.7-7.1	21.74(9.83) 8.7-36	12.6(6.21) 8-19	2.13(.91) .87-3.4

(1) Source, Department of Fisheries and Oceans, Habitat Protection Division, Water Quality Unit. Unpublished data.

TABLE 61

METAL CONCENTRATION IN INVERTEBRATES[1]

Site[2]		Date	Sample Type	Hg (µg/g) Dry Wt.	Cu (µg/g) Dry Wt.
11	chlor-alkali plant beach (east)	1978	Idothea (Isopod sp.)	0.50	232
12	chlor-alkali plant of barge slip	1979	Idothea (Isopod sp.)	0.40	-
		1979	Mytilus sp. (Mussel)	4.80	-
13	Shannon Gravel	1978	Idothea (Isopod sp.)	<0.25	676
14	Furry Creek	1978	Idothea (Isopod sp.)	<0.25	504
16	chlor-alkali plant beach (west)	1979	Clams	12.80	-

[1] Source: Ministry of Environment, Waste Management Branch, Regional Office, Surrey, Unpublished data.

[2] Location of sample sites are presented in Figures 27 and 33

Minimum sample size 10 gms wet weight

TABLE 62

METAL CONCENTRATION IN *Fucus gardneri* [1,2]

Site[3]	Date	Hg(µg/g wet-wt.)	Cu (µg/g dry wt.)	Zn (µg/g dry wt.)
F1. ∿2km south of west delta of Squamish R.	1974	0.25	149	149
	1976	< 0.25	22.1	164
F2. chlor-alkali plant	1974	0.25	30.5	90.3
	1976	< 0.25	16.3	116
F3. ∿4km south of Mamquam Channel mouth (ferry terminal)	1974	0.25	53.1	142
	1976	< 0.25	24.1	152
F4. Brittania	1974	< 0.25[4]	-	-
F5. Shannon Creek	1974	< 0.25[4]	-	-

1 Source: Ministry of Environment, Waste Management Branch, Regional Officer, Surrey, Unpublished data.

2 Approximate sample size, 225 grams, wet weight

3 Location of sample sites shown in Figures 27 and 33

4 Gough, G.R. in Garrett, C. et al., In Press; Mercury in British Columbia and Yukon Environments - Summary of Data to January 1, 1979.

TABLE 63

CHLOROPHENOL, CHLOROBENZENE, CHLOROANISOLE CONCENTRATION IN BIOTA[1]

Site[1]	Sample Type	Number Samples	Contaminant	Concentration µg/kg (wet wt.)	Bioaccumulation factor from sediment
Empire mills	staghorn	4	pentachlorophenol	tr/35	.02-.1/.66
Weldwood	sculpins	4	tetrachlorophenol	9/63	.09/.64
(Mamquam Channel)	(Leptocottus armatus)	4	trichlorophenol	ND/ND	-
		4	hexachlorophenol	ND/54	-
	(muscle/liver	4	pentachlorobenzene	ND/ND	-
	tissue)	4	tetrachlorophenol	ND/ND	-
			pentachloroanisole	ND/tr	-
	crab-(cancer magister) (muscle tissue)	10	pentachlorophenol	<1	<0.02
		10	tetrachlorophenol	8	0.08
		10	trichlorophenol	ND	-
		10	hexachlorophenol	tr	-
		10	pentachlorobenzene	ND	-
		10	tetrachlorobenzene	ND	-
		10	pentachloroanisole	ND	-

ND - not detected (approximately ½ of limit of quantitation)
tr - present but below limit of quantitation

limits of quantitation: chlorophenols 5 µg/kg
chlorobenzenes 0.5 µg/kg
pentachloroanisole 0.5 µg/kg

Sampled November 27, 1978

[1] Source: DOE, EPS (1979)

TABLE 64

FISH KILLS: 1971-1978[1]

Location[2]	Month/Year	Species	Estimated Number	Cause	Circumstances
Squamish Harbour	February 1971	no data	100	hydrogen sulphide	Dredging
Squamish Harbour	June 1971	no data	no data	chlorine	Chlorine spill
Mamquam Blind Channel	October 1973	adult & juvenile coho shiner	500 500	pentachlorophenol and tetrachlorophenol	lumber treatment tank overflowed (Note: charged and convicted).
Mamquam Blind Channel	June 1975	juvenile herring	3000	unknown	
Mamquam Blind Channel	October 1977	coho jacks	no data	tetrachlorophenol & pentachlorophenol	probably due to spillage of wood preservation from dip tank at Weldwood. Analysis of flesh of jacks showed toxic level of preservatives.

[1] Source: Department of Fisheries and Oceans, Habitat Protection Division, Water Quality. Unpublished records.

[2] Refer to Figure 33

TABLE 65

1980 ANALYTICAL RESULTS

TRACE ORGANIC CONTAMINANTS

SUBSTANCE	SITE			DETECTION LIMIT
	WELDWOOD YARD DRAINAGE	FMC EFFLUENT	MAMQUAM STP EFFLUENT	
Miscellaneous Parameters				
pH	6.05	7.2	7.05	-
Suspended Solids (mg/L)				
Fixed	5	25	3	2.0
Volatile	4	13	20	2.0
Specific Conductance (umhos/cm)	64.2	39 400	375	-
Total Phenols (mg/L)	0.021	-	0.025	0.001
Oil and Grease (mg/L)	-	-	-	2.0
Total Organic Carbon (mg/L)	15	-	22	2.0
Volatile Compounds (Purgeables) (ug/L)				
Acrolein	-	-	-	2.0
Acrylonitrile	-	-	-	2.0
Benzene	-	-	-	2.0
Bromodichloromethane	-	-	-	2.0
Bromoform	-	6.5	-	2.0
Bromomethane	-	-	-	2.0
Carbon Tetrachloride	-	-	-	2.0
Chlorobenzene	-	-	-	2.0
Chloroethane	-	-	-	2.0
2-Chloroethylvinyl ether	-	-	-	2.0
Chloroform	20.0	1.7	3.1	2.0
Chloromethane	-	-	-	2.0
bis-Chloromethyl ether	-	-	-	2.0
Dibromochloromethane	-	-	-	2.0
Dichlorodifluoromethane	-	-	-	2.0
1, 1 - Dichloroethane	-	-	-	2.0
1, 2 - Dichloroethane	-	-	-	2.0
1, 1 - Dichloroethylene	-	-	-	2.0
trans - 1, 2-Dichloroethylene	-	-	-	2.0
1, 2 - Dichloropropane	-	-	-	2.0
1, 2 - Dichloropropylene	-	-	-	2.0
Ethylbenzene	-	-	-	2.0
Methylene Chloride	10.0	2.5	-	2.0
1,1,2,2-Tetrachloroethane	-	-	-	2.0
1,1,2,2-Tetrachloroethene	-	-	-	2.0
Toluene	-	TRACE	-	2.0
1,1,1-Trichloroethane	-	-	-	2.0
1,1,2-Trichloroethane	-	-	13.0	2.0
Trichloroethylene	-	-	16.0	2.0
Trichlorofluoromethane	-	-	-	2.0
Vinyl Chloride	-	-	-	-

TABLE 65 (CONTINUED)

SUBSTANCE	SITE			DETECTION LIMIT
	WELDWOOD YARD DRAINAGE	FMC EFFLUENT	MAMQUAM STP EFFLUENT	
Base Neutral Extractable Compounds (ug/L)				
Acenaphthene	-	-	-	10.0
Acenaphthylene	-	-	-	10.0
Anthracene	-	-	-	10.0
Benzidine	-	-	-	10.0
Benzo (a) anthracene	-	-	-	10.0
Benzo (b) fluoranthene	-	-	-	10.0
Benzo (k) fluoranthene	-	-	-	10.0
Benzo (ghi) perylene	-	-	-	10.0
Benzo (a) pyrene	-	-	-	10.0
4-Bromo-phenyl phenyl ether	-	-	-	10.0
Butyl Benzylphathalate	TRACE	TRACE	TRACE	10.0
bis (2-Chloroethoxy) methane	-	-	-	10.0
bis (2-Chloroethyl) ether	-	-	-	10.0
bis (2-Chloroisopropyl) ether	-	-	-	10.0
2-Chloronaphthalene	-	-	-	10.0
4-Chloro-phenyl phenyl ether	-	-	-	10.0
Chrysene	-	-	-	10.0
Dibenzo (ah) anthracene	-	-	-	10.0
Di-n-butylphthalate	TRACE	TRACE	TRACE	10.0
1, 2 - Dichlorobenzene	-	-	-	10.0
1,3 - Dichlorobenzene	-	-	TRACE	10.0
1,4 - Dichlorobenzene	-	-	-	10.0
3,3' - Dichlorobenzidine	-	-	-	10.0
Diethylphthalate	TRACE	TRACE	TRACE	10.0
Dimethylphthalate	TRACE	TRACE	TRACE	10.0
2,4 - Dinitrotoluene	-	-	-	10.0
2,6 - Dinitrotoluene	-	-	-	10.0
Di-n-octylphthalate	-	-	1.7	10.0
1, 2 - Diphenylhydrazine	-	-	-	10.0
bis (2-ethylhexyl) phthalate	13	39	32	10.0
Fluoranthene	-	-	-	10.0
Fluorene	-	-	-	10.0
Hexachlorobenzene	-	-	-	10.0
Hexachlorobutadiene	-	-	-	10.0
Hexachlorocyclopentadiene	-	-	-	10.0
Hexachloroethane	-	-	-	10.0
Indeno (1,1,2 - cd) pyrene	-	-	-	10.0
Isophorone	-	-	-	10.0
Naphthalene	TRACE	-	TRACE	10.0
Nitrobenzene	-	-	-	10.0

TABLE 65 (CONTINUED)

SUBSTANCE	SITE			DETECTION LIMIT
	WELDWOOD YARD DRAINAGE	FMC EFFLUENT	MAMQUAM STP EFFLUENT	
N-nitrosodimethylamine	-	-	-	10.0
N-nitrosodiphenylamine	-	-	-	10.0
N-nitrosodi-n-propylamine	-	-	-	10.0
Phenanthrene	-	-	-	10.0
Pyrene	-	-	-	10.0
2,3,7,8-tetrachlorodibenzo-p-dioxin	-	-	-	10.0
1,2,3 -trichlorobenzene	-	-	-	10.0
Acid Extractable Compounds (ug/L)				
p - Chloro - m - cresol	-	-	-	10.0
2 - Chlrophenol	-	-	-	10.0
2, 4, - Dichlorophenol	-	-	-	10.0
2, 4, - Dimethylphenol	-	-	-	10.0
4, 6, - Dinitro-o-cresol	-	-		100.0
2, 4, - Dinitrophenol	-	-	-	100.0
2 - Nitrophenol	-	-	-	10.0
4 - Nitrophenol	-	-	-	10.0
Pentachlorophenol	TRACE	-	TRACE	10.0
Phenol	-	-	-	10.0
2, 3, 6 - Trichlorophenol	-	-	-	10.0
Pesticides and Polychlorinated Biphenyls (ug/L)				
Aldrin	0.005	-	-	0.003
Benzene Hexachloride - alpha	0.045	-	-	0.002
- beta	-	-	-	0.004
- gamma	0.058	0.045	0.059	0.002
- delta	-	-	-	0.004
Chlordane	-	-	-	0.04
4, 4' - DDD	-	-	-	0.012
4, 4' - DDE	-	-	-	0.006
4, 4' - DDT	-	-	-	0.016
alpha - Endosulfan	-	-	-	0.005
Dieldrin	-	-	-	0.006
beta - Endosulfan	-	-	-	0.010
Endosulfan Sulphate	-	-	-	0.03
Endrin	-	-	-	0.009
Endrin Aldehyde	-	-	-	0.023
Heptachlor	-	-	-	0.002
Heptachlor Epoxide	-	-	-	0.004
Polychlorinated Biphenyls (PCB)				
- Arochlor - 1016	-	-	-	0.04
- 1221	-	-	-	0.10
- 1232	-	-	-	0.10
- 1242	-	-	-	0.05
- 1248	-	-	-	0.08

TABLE 65 (CONTINUED)

SUBSTANCE	SITE			DETECTION LIMIT
	WELDWOOD YARD DRAINAGE	FMC EFFLUENT	MAMQUAM STP EFFLUENT	
- Arochlor - 1254	-	-	-	0.08
- 1260	-	-	-	0.15
Toxaphenes	-	-	-	0.40

- Less than Detection Limit

TRACE: Substance was detected but at such a small concentration as to preclude accurate quantitation.

TABLE 66

WIND DIRECTION PERCENTAGE FREQUENCY VERSUS/
TIME OF THE DAY AT LANGDALE FERRY TERMINAL, AUGUST TO OCTOBER 1980

Wind Direction	Hour																								All
	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
N	6	4	4	6	2	4	16	30	35	22	11	10	12	16	18	30	17	11	14	4	5	6	3	8	12
NE	0	0	0	0	0	0	3	8	5	1	3	2	1	1	2	1	0	0	0	0	0	0	0	0	1
E	0	0	1	0	0	0	1	6	15	11	8	3	4	5	6	1	6	1	0	0	0	0	0	0	3
SE	0	0	0	0	0	0	0	9	16	22	17	15	9	7	6	7	0	1	0	0	0	0	0	0	5
S	1	1	2	2	3	4	4	10	16	37	52	64	69	61	55	42	34	25	5	3	0	1	1	2	21
SW	0	1	1	2	1	3	8	6	6	2	1	0	0	4	3	6	11	5	17	4	1	1	2	2	4
W	78	84	89	85	86	78	54	24	3	1	0	0	2	3	4	5	22	43	49	74	75	76	85	77	46
NW	14	10	6	4	7	10	13	8	4	4	8	5	2	2	4	8	11	13	14	14	19	15	9	11	9

Appendix A

APPENDIX A

ACIDITY - ALKALINITY SURVEY

In order to determine the buffering capacity of waters within the study area for discharges of strong acids or bases, samples were collected at the locations indicated in Figure 34. The results of the titrations using strong acid (0.125 N HNO_3) and strong base (0.125 N NaOH), are included in Table A-3 and are plotted in Figures A-1 to A-5. As well, titrations of distilled water and ocean water with a salinity of 30 ppt, were performed. The results are included in Tables A-1 and A-2, and are plotted as Figures A-6 and A-7. The distilled water was also titrated using $CH_3CO(OH)$ and NH_4OH.

The results in Figure A-1 indicate that the furthest upstream Squamish River station 1 was the best buffered of the three Squamish River stations against alkaline discharges. This was not the case for acidic discharges, where Squamish River stations 1 and 3 were found to be approximately, equally well buffered. The Mamquam River is somewhat better buffered against acidic discharges, and its influence is apparent in data for Squamish River station 2.

Squamish River stations 4, 5 and 6, plotted in Figure A-2, reflect the presence of riverine waters in their surface waters, while samples from depth reflected the influence of Howe Sound waters. In fact, samples from depth were similar to station P ocean water. However, there was little difference in buffering capacities for these stations either at depth or at surface. Proposed discharges of acidic or alkaline wastes near these stations should be made from submerged outfalls.

Samples were collected from three stations, and at two depths at each station, in Cattermole Creek. The samples were titrated, and the results were plotted as Figure A-3. Both surface samples, and samples from depth, were saline. Although the samples at both depths from the three stations were equally well buffered against alkaline discharges, samples from depths at the three stations were better buffered against acidic discharges than the surface samples. Buffering capacities for acids were not as good as for station P ocean water, but similar in buffering capacity for bases.

Samples were collected from four stations, at two depths, in the Mamquam Blind Channel. The samples were titrated, and the results are plotted in Figures A-4 and A-5. The data indicate that the more saline samples, collected at depths below the surface, were better buffered against both acidic and alkaline discharges, than surface water samples which had lower salinities. Thus, acidic or alkaline discharges into Mamquam Blind Channel should be made through submerged outfalls. Samples collected at depth were as well buffered as samples from Cattermole Creek, but surface samples were not as well buffered as station P ocean water.

The type of acid used for titrations, either HNO_3 or $CH_3CO(OH)$, became more significant in determining the resultant pH, as larger equivalents of acid were titrated. The HNO_3 was a stronger acid than the $CH_3CO(OH)$ for both distilled water and sea water samples. The HNO_3 produced lower pH values at equal equivalents of acid.

The type of base used for titration, either NaOH or NH_4OH, determined the pH of the sample along with the type of sample. Distilled water was better buffered against NH_4OH than against NaOH, while the ocean water samples were better buffered against the NaOH.

FIGURE A-1. TITRATION OF 100 mL SAMPLES WITH STANDARDIZED HNO_3 AND NaOH .

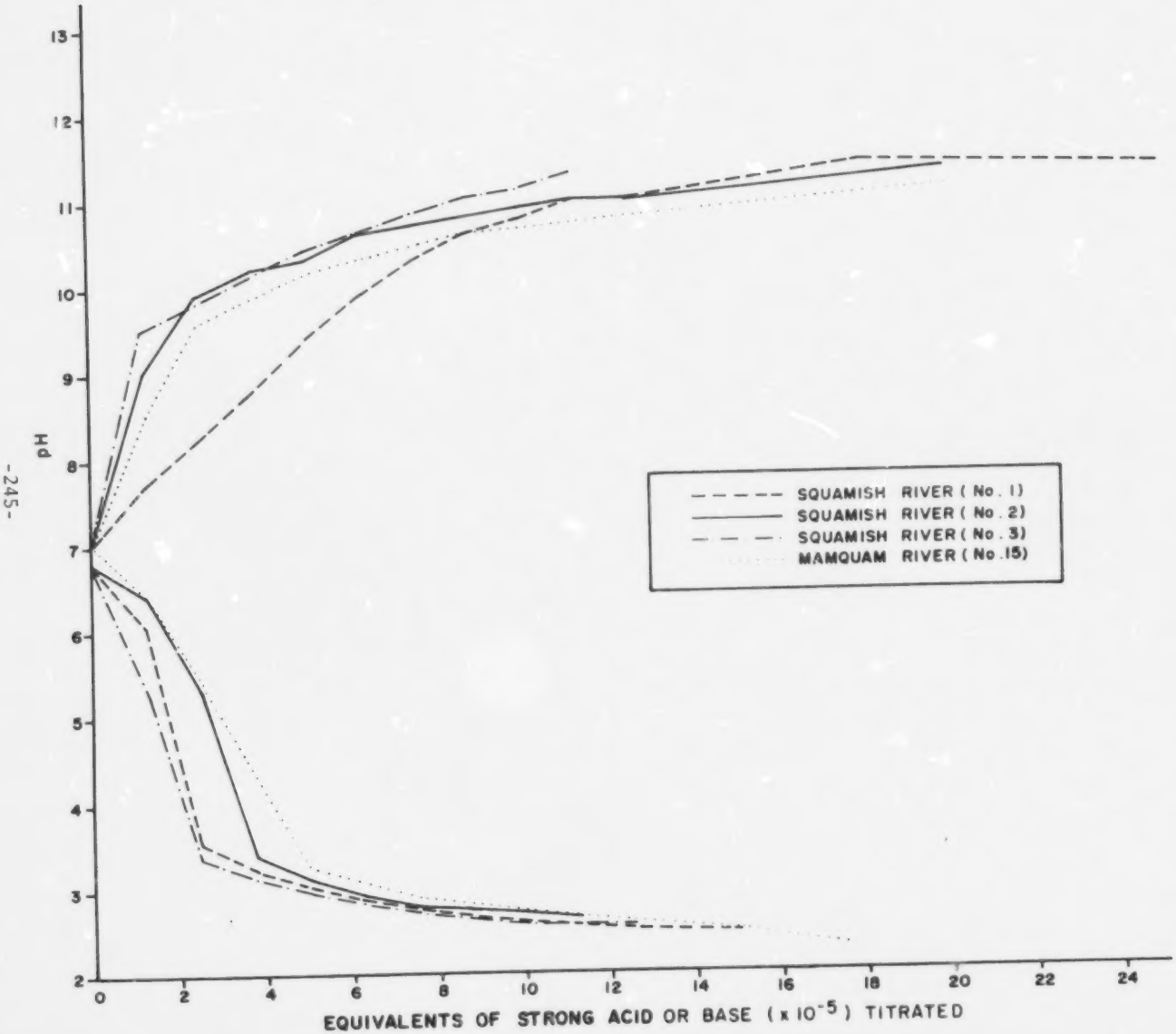

pH
EQUIVALENTS OF STRONG ACID OR BASE (x 10⁻⁵) TITRATED
SQUAMISH RIVER (No. 1)
SQUAMISH RIVER (No. 2)
SQUAMISH RIVER (No. 3)
MAMQUAM RIVER (No. 15)

FIGURE A-2. TITRATION OF 100 mL SAMPLES WITH STANDARDIZED HNO_3 AND NaOH . SQUAMISH RIVER .

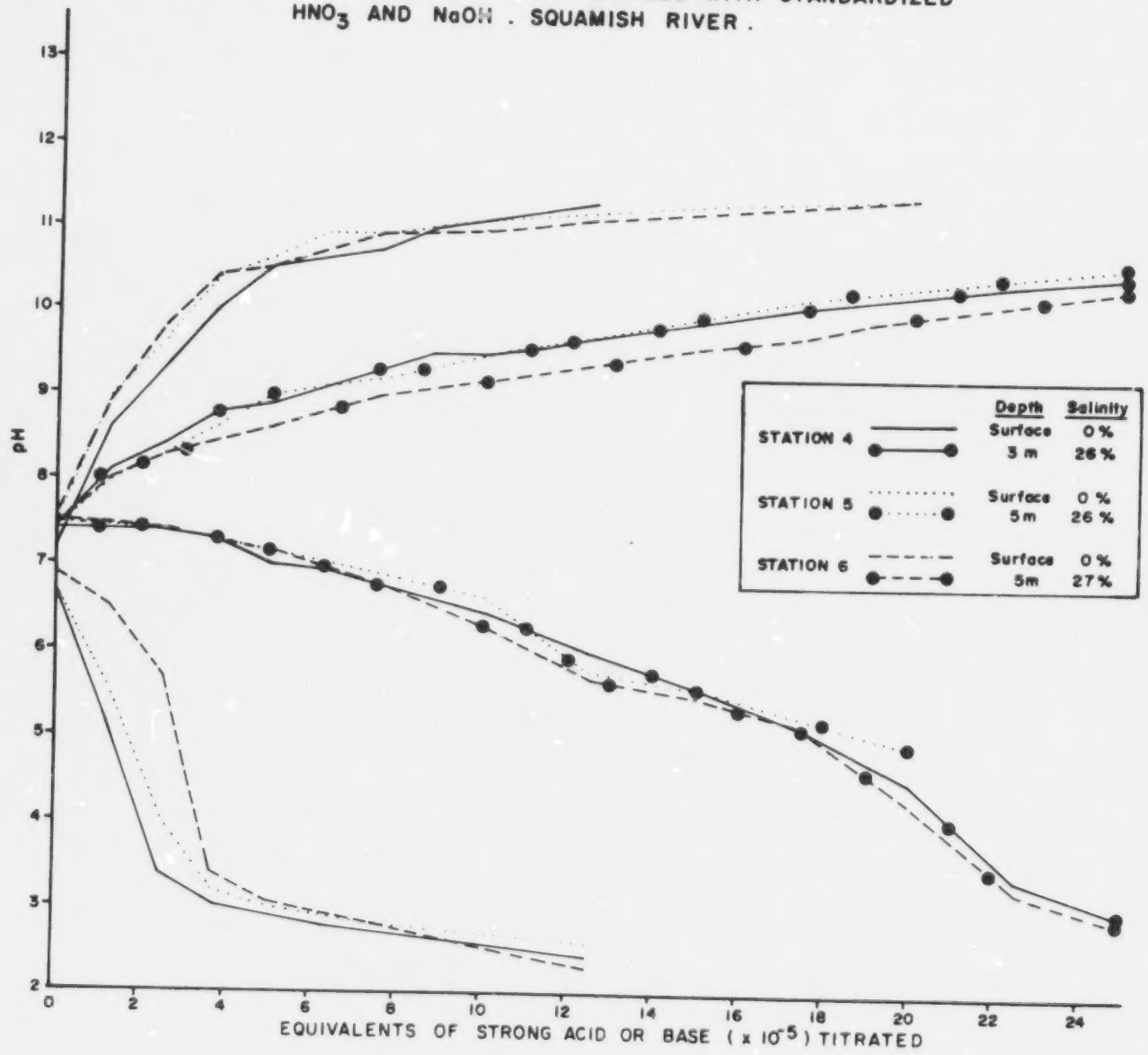


FIGURE A-3. TITRATION OF 100 mL SAMPLES WITH STANDARDIZED HNO_3 AND NaOH. CATTERMOLE CREEK.

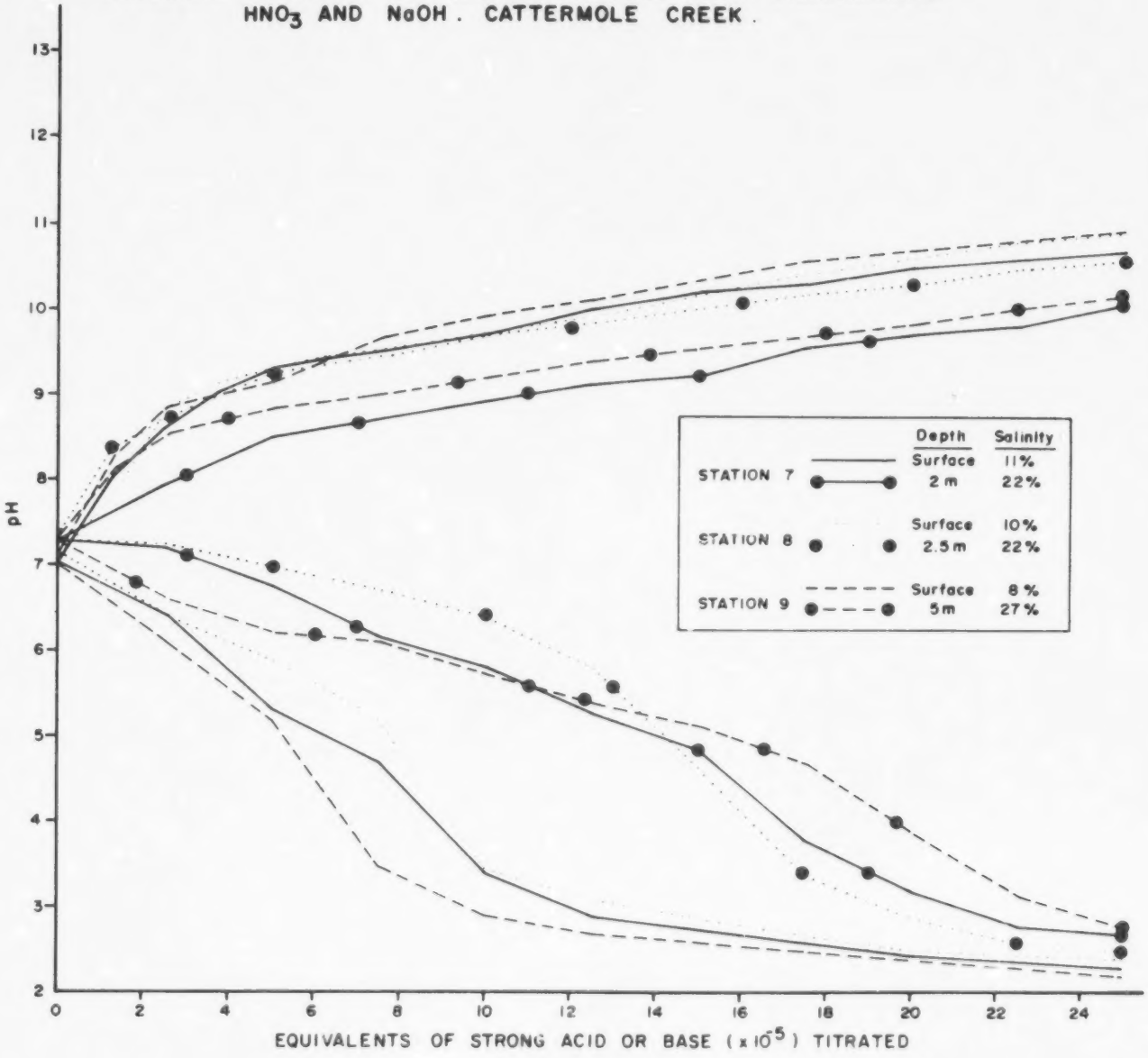


FIGURE A-4. TITRATION OF 100 mL SAMPLES WITH STANDARDIZED HNO_3 AND NaOH. MAMQUAM BLIND CHANNEL.

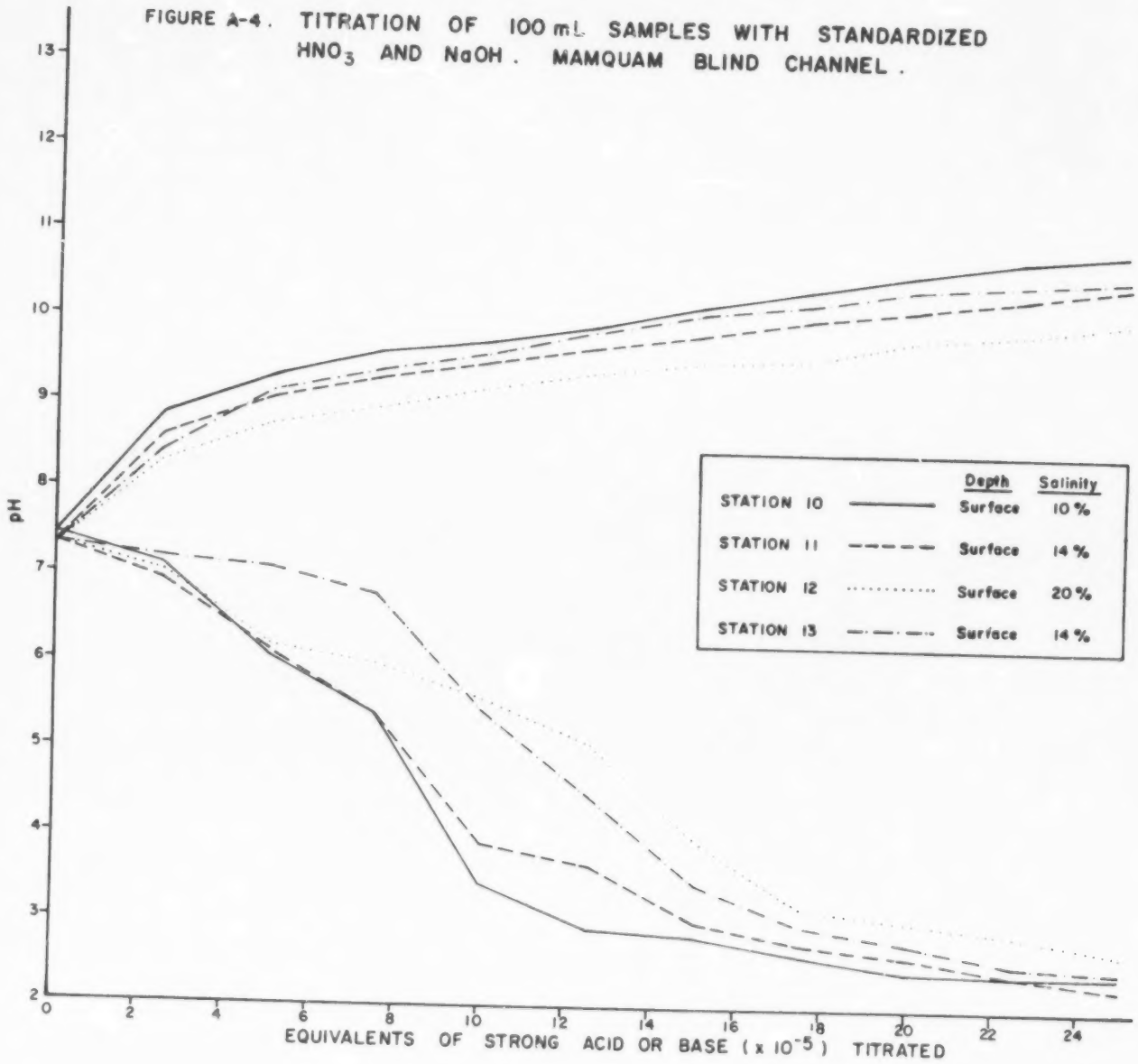


FIGURE A-5. TITRATION OF 100 mL SAMPLES WITH STANDARDIZED HNO_3 AND NaOH. MAMQUAM BLIND CHANNEL.

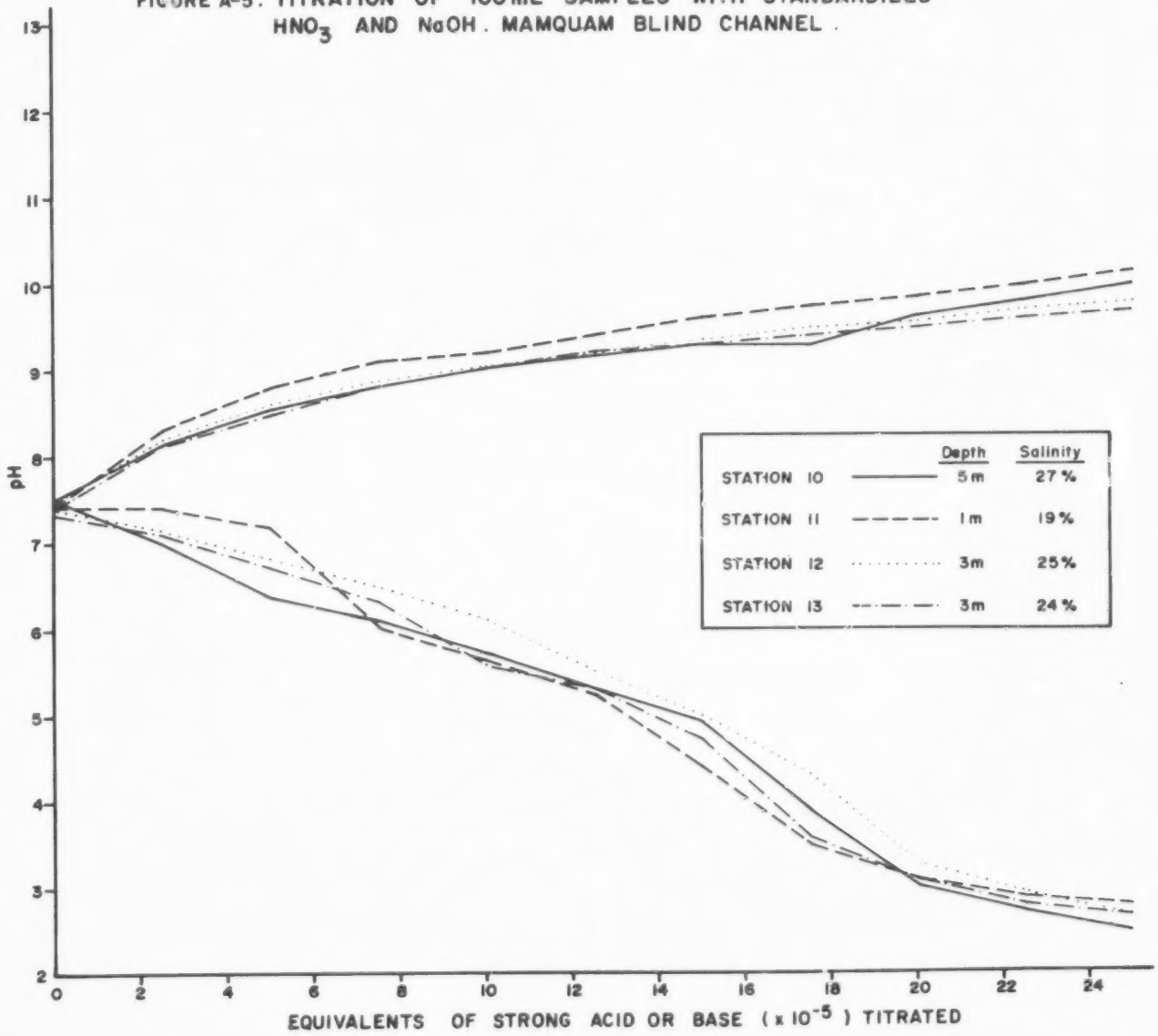


FIGURE A-6. TITRATION OF 100 mL DISTILLED WATER SAMPLES WITH STANDARDIZED HNO_3, NaOH, NH_4OH, and $CH_3CO(OH)$.

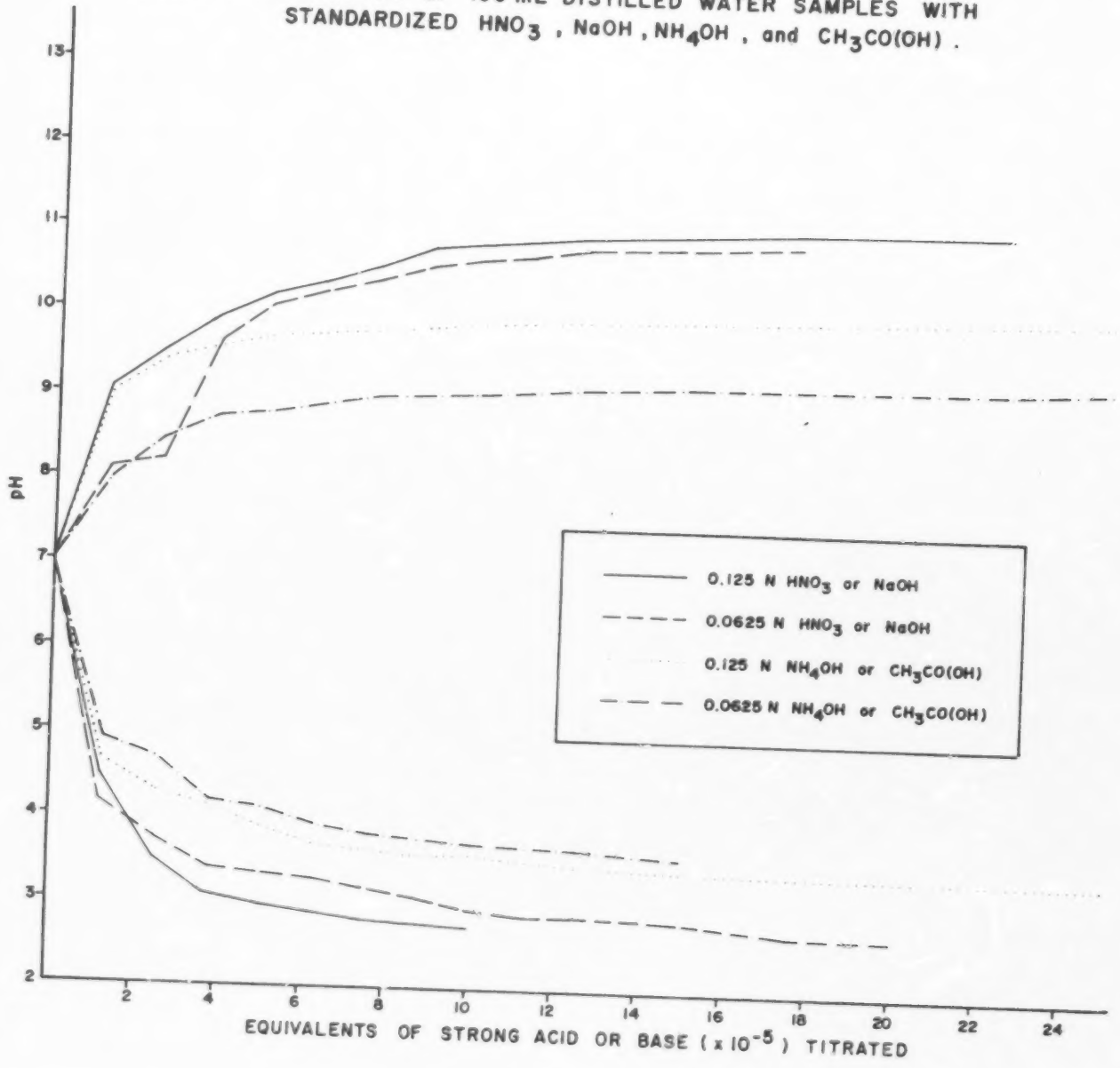
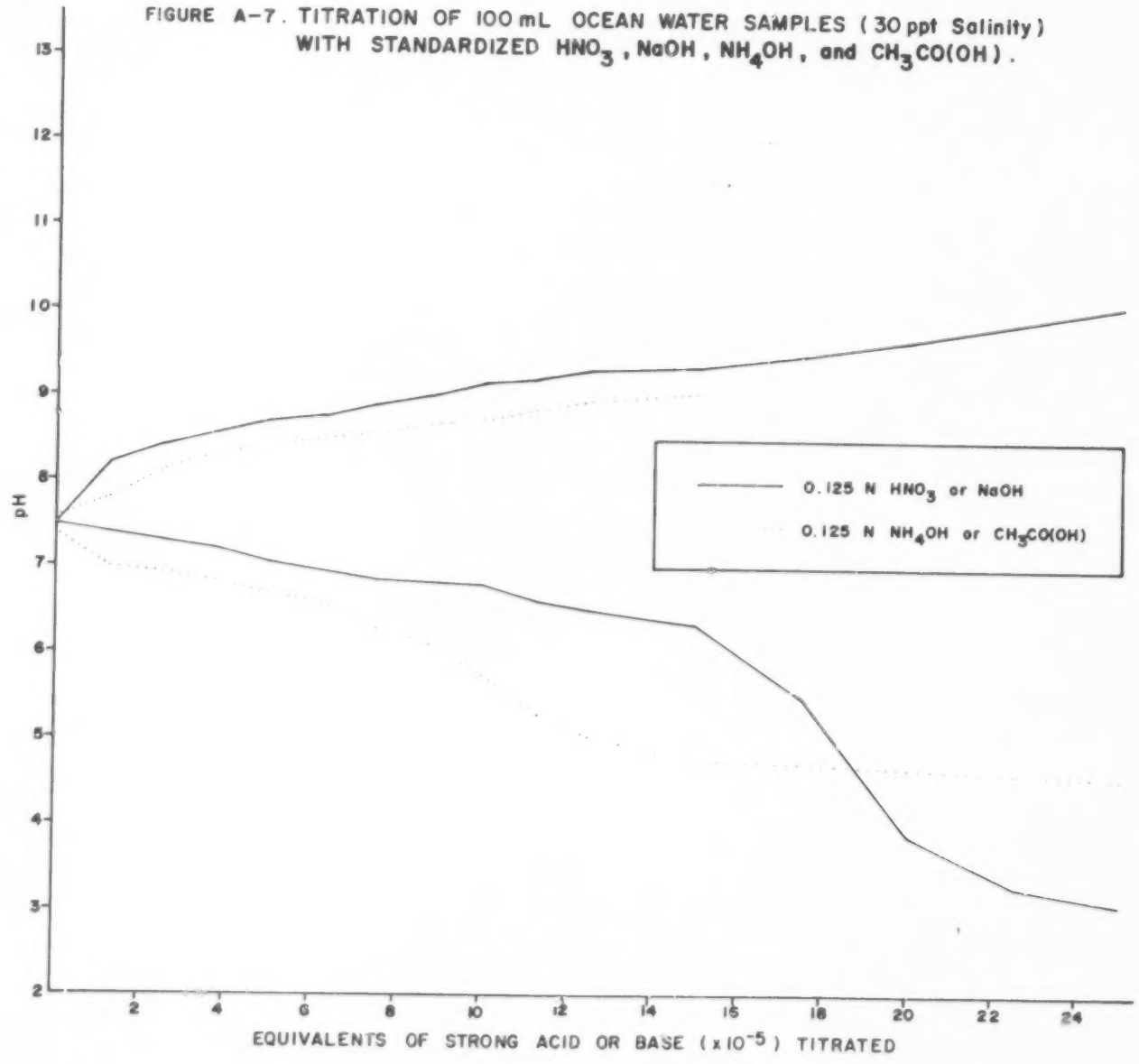


FIGURE A-7. TITRATION OF 100 mL OCEAN WATER SAMPLES (30 ppt Salinity) WITH STANDARDIZED HNO_3, NaOH, NH_4OH, and $CH_3CO(OH)$.



Notes:

1. Ocean water from station P, collected by the Institute of Ocean Sciences on cruise 80-005; July 20, 1980.

2. pH meter used in all titrations - Orion analyser
   Model 407A
   Specific Ion Meter
   Fisher Scientific pH
   probe (0-14)

TABLE A-1

RESULTS OF TITRATION OF 100 mL SAMPLES

WITH HNO_3 AND NaOH

Volume of 0.125 N Acid or Base	Equivalents ($\times 10^{-5}$)	% By Volume	Resultant pH Values with Base or Acid Addition					
			Distilled Water				Ocean Water (Salinity-30 ppt)	
			.125 N Acid Added	.125 N Base Added	.0625 N Acid Added	.0625 N Base Added	.125 N Acid Added	.125 N Base Added
0.0	0.0	0.0	7.0	7.0	7.0	7.0	7.55	7.5
0.1	1.25	0.1	4.5	9.05	4.2	8.1	7.4	8.2
0.2	2.5	0.2	3.5	9.5	3.75	8.22	7.3	8.4
0.3	3.75	0.3	3.1	9.9	3.4	9.63	7.2	8.55
0.4	5.0	0.4	3.0	10.2	3.35	10.07	7.05	8.7
0.5	6.25	0.5	2.9	10.35	3.3	10.27	6.95	8.75
0.6	7.5	0.6	2.8	10.55	3.2	10.4	6.85	8.9
0.7	8.75	0.7	2.78	10.8	3.1	10.55	6.8	9.0
0.8	10.	0.8	2.75	10.85	2.95	10.65	6.8	9.15
0.9	11.25	0.9		10.9	2.9	10.7	6.6	9.2
1.0	12.5	1.0		10.95	2.9	10.8	6.5	9.3
1.2	15.0	1.2		11.0	2.85	10.85	6.35	9.35
1.4	17.5	1.4		11.05	2.7	10.9	5.5	9.5
1.6	20.0	1.6			2.7		3.9	9.7
1.8	22.5	1.8		11.1			3.3	9.9
2.0	25.0	2.0					3.1	10.1

TABLE A-2

RESULTS OF TITRATION OF 100 mL SAMPLES

WITH NH_4OH and $CH_3CO(OH)$

Volume of 0.125 N Acid or Base	Equivalents ($\times 10^{-5}$)	% By Volume	Resultant pH Values with Base or Acid Addition					
			Distilled Water				Ocean Water (Salinity-30 ppt)	
			.125 N Acid Added	.125 N Base Added	.0625 N Acid Added	.0625 N Base Added	.125 N Acid Added	.125 N Base Added
0.0	0.0	0.0	7.0	7.0	7.0	7.0	7.6	7.4
0.1	1.25	0.1	4.7	9.0	4.9	8.0	7.0	7.8
0.2	2.5	0.2	4.3	9.4	4.7	8.45	6.95	8.15
0.3	3.75	0.3	4.15	9.6	4.2	8.75	6.85	8.3
0.4	5.0	0.4	3.9	9.7	4.15	8.8	6.7	8.4
0.5	6.25	0.5	3.7	9.75	3.95	8.9	6.6	8.5
0.6	7.5	0.6	3.65	9.8	3.85	9.0	6.3	8.55
0.7	8.75	0.7	3.6		3.8		6.1	8.65
0.8	10.	0.8	3.6	9.9	3.75	9.05	5.75	8.7
0.9	11.25	0.9					5.3	8.85
1.0	12.5	1.0	3.5	9.95	3.7	9.15	5.05	8.95
1.2	15.0	1.2	3.45		3.6		4.8	9.05
1.4	17.5	1.4				9.2	4.75	
1.6	20.0	1.6						
1.8	22.5	1.8				9.25		
2.0	25.0	2.0	3.4	10.1	3.5	9.3	4.6	

TABLE A-3

RESULTS OF TITRATION OF 100 mL SAMPLES

WITH HNO_3 AND NaOH

Volume of 0.125 N Acid or Base	Equivalents ($\times 10^{-5}$)	% By Volume	Resultant pH Values with Base or Acid Addition					
			Station No. 1		Station No. 2		Station No. 15	
			Surface		Surface		Surface	
			Acid Added	Base Added	Acid Added	Base Added	Acid Added	Base Added
0.0	0.0	0.0	6.8	6.8	6.8	6.9	7.0	7.2
0.1	1.25	0.1	6.05	7.7	6.4	9.0		8.45
0.2	2.5	0.2	3.55	8.2	5.3	9.9	5.4	9.55
0.3	3.75	0.3	3.20	8.7	3.4	10.2		9.85
0.4	5.0	0.4	3.04	9.4	3.1	10.3	3.3	10.15
0.5	6.25	0.5	2.90	9.9	2.93	10.6		
0.6	7.5	0.6	2.81	10.3	2.82	10.7	2.9	10.45
0.7	8.75	0.7	2.72	10.6	2.75	10.8		
0.8	10.	0.8	2.65	10.75	2.70	10.9	2.7	10.65
0.9	11.25	0.9	2.57	11.0	2.65	11.0		
1.0	12.5	1.0	2.52	11.0		11.1	2.6	10.8
1.2	15.0	1.2	2.48	11.1			2.5	
1.4	17.5	1.4					2.3	
1.6	20.0	1.6		11.4		11.3		11.1
1.8	22.5	1.8						
2.0	25.0	2.0		11.3				

Station Descriptions

Station 1 - Squamish River at Boys School (80/09/15)
- Surface - Salinity 0 ppt

Station 2 - Squamish River Below Mamquam Island (80/09/15)
- Surface - Salinity 0 ppt

Station 15 - Mamquam River at Old Highway Bridge (80/09/15)
Surface - Salinity 0 ppt

TABLE A-3 (CONTINUED)

RESULTS OF TITRATION OF 100 mL SAMPLES WITH HNO_3 AND NaOH

Volume of 0.125 N Acid or Base	Equivalents ($\times 10^{-5}$)	% By Volume	Resultant pH Values with Base or Acid Addition							
			Station No. 3				Station No. 4			
			Surface		m Depth		Surface		3 m Depth	
			Acid Added	Base Added	Acid Added	Base Added	Acid Added	Base Added	Acid Added	Base Added
0.0	0.0	0.0	6.8	6.9			6.7	6.9	7.4	7.4
0.1	1.25	0.1	5.25	9.5			5.15	8.6	7.4	8.1
0.2	2.5	0.2	3.4	9.7			3.4	9.3	7.4	8.4
0.3	3.75	0.3	3.15	10.2			3.0	10.0	7.3	8.8
0.4	5.0	0.4	2.98	10.4			2.9	10.5	7.0	8.9
0.5	6.25	0.5	2.85	10.6			2.8	10.6	6.94	9.0
0.6	7.5	0.6		10.8				10.7	6.85	9.3
0.7	8.75	0.7		11.0				11.0	6.78	9.5
0.8	10.	0.8		11.1				11.1	6.5	9.5
0.9	11.25	0.9		11.3				11.3		9.6
1.0	12.5	1.0	2.55						6.0	9.7
1.2	15.0	1.2							5.6	9.9
1.4	17.5	1.4								10.1
1.6	20.0	1.6							4.5	
1.8	22.5	1.8							3.4	10.4
2.0	25.0	2.0							3.0	

Station Descriptions

Station 3 - Squamish River at Central Basin Culverts (80/09/15)
- Surface - Salinity 0 ppt

Station 4 - Squamish River, Downstream of dolphin Below Island (80/09/15)
- Surface - Salinity 0 ppt
- 3 Metre Depth - Salinity 26 ppt

TABLE A-3 (CONTINUED)

RESULTS OF TITRATION OF 100 mL SAMPLES WITH

HNO_3 AND NaOH

Volume of 0.125 N Acid or Base	Equivalents ($\times 10^{-5}$)	% By Volume	Resultant pH Values with Base or Acid Addition							
			Station No. 5				Station No. 6			
			Surface		5 m Depth		Surface		5 m Depth	
			Acid Added	Base Added	Acid Added	Base Added	Acid Added	Base Added	Acid Added	Base Added
0.0	0.0	0.0	6.7	6.9	7.4	7.4	6.9	6.9	7.5	7.4
0.1	1.25	0.1	5.55	9.0	7.4	8.0	6.5	8.9		8.05
0.2	2.5	0.2	4.0	9.6	7.4	8.3	5.7	9.8	7.4	8.3
0.3	3.75	0.3	3.2	10.4		8.6	3.4	10.4		
0.4	5.0	0.4	3.0	10.6	7.15	9.0	3.05	10.5	7.2	8.6
0.5	6.25	0.5	2.9	10.9		9.1	2.9	10.7		
0.6	7.5	0.6	2.8	10.9	6.9	9.2	2.8	10.9	6.85	9.0
0.7	8.75	0.7								
0.8	10.	0.8		11.1	6.65	9.5		11.0	6.3	9.2
0.9	11.25	0.9								
1.0	12.5	1.0	2.6	11.2	5.8	9.7		11.1	5.7	9.4
1.2	15.0	1.2		11.3	5.6		2.3		5.5	9.6
1.4	17.5	1.4							5.15	9.75
1.6	20.0	1.6		11.4	4.95	10.2		11.4	4.3	9.95
1.8	22.5	1.8							3.25	10.2
2.0	25.0	2.0				10.6			2.9	10.35

Station Descriptions

Station 5 - Squamish River, Mouth, 30 Metres S.W. of Dyke
- Surface - Salinity 0 ppt
- 5 Metre Depth - Salinity 26 ppt

Station 6 - Squamish River, Mouth, Between Granite Cliff and Small Island
- Surface - Salinity 0 ppt
- 5 Metre Depth - Salinity 27 ppt

TABLE A-3 (CONTINUED)

RESULTS OF TITRATION OF 100 mL SAMPLES WITH HNO_3 AND NaOH

Volume of 0.125 N Acid or Base	Equivalents ($\times 10^{-5}$)	% By Volume	Resultant pH Values with Base or Acid Addition							
			Station No. 7				Station No. 8			
			Surface		2 m Depth		Surface		2.5 m Depth	
			Acid Added	Base Added	Acid Added	Base Added	Acid Added	Base Added	Acid Added	Base Added
0.0	0.0	0.0	7.0	7.0	7.3	7.0	7.15	7.0	7.3	7.4
0.1	1.25	0.1		8.0				7.8		8.3
0.2	2.5	0.2	6.4	8.6	7.2	7.9	6.4	8.8	7.3	8.7
0.3	3.75	0.3		9.0				9.1		
0.4	5.0	0.4	5.2	9.2	6.75	8.5	5.9		6.95	9.2
0.5	6.25	0.5		9.4						
0.6	7.5	0.6	4.7	9.5	6.15	8.7	5.2	9.5	6.7	9.5
0.7	8.75	0.7								
0.8	10.	0.8	3.4	9.7	5.8	8.9	3.45	9.7	6.4	9.7
0.9	11.25	0.9								
1.0	12.5	1.0	2.9	10.0	5.25	9.1	3.1	9.9	5.8	9.85
1.2	15.0	1.2	2.75	10.2	4.85	9.2	2.9	10.2	4.65	10.0
1.4	17.5	1.4	2.6	10.3	3.8	9.55	2.7	10.4	3.4	10.2
1.6	20.0	1.6	2.45	10.5	3.2	9.7	2.5	10.6	2.9	10.3
1.8	22.5	1.8		10.6	2.8	9.8		10.8	2.6	10.5
2.0	25.0	2.0	2.3	10.7	2.7	10.1	2.4	10.9	2.5	10.6

Station Descriptions

Station 7 - Cattermole Creek
- North of FMC North Fenceline
- 2 m Depth - Salinity 22 ppt

Station 8 - Cattermole Creek
- Parallel to FMC Outfall
- Surface - Salinity 10 ppt
- 2.5 m Depth - Salinity 22 ppt

TABLE A-3 (CONTINUED)

RESULTS OF TITRATION OF 100 mL SAMPLES WITH HNO_3 AND NaOH

Volume of 0.125 N Acid or Base	Equivalents ($\times 10^{-5}$)	% By Volume	Resultant pH Values with Base or Acid Addition							
			Station No. 9				Station No. 10			
			Surface		5 m Depth		Surface		5 m Depth	
			Acid Added	Base Added	Acid Added	Base Added	Acid Added	Base Added	Acid Added	Base Added
0.0	0.0	0.0	7.3	7.2	7.4	7.35	7.5	7.2	7.5	7.35
0.1	1.25	0.1		8.3		8.1				
0.2	2.5	0.2	6.1	8.8	6.6	8.55	7.15	8.85	7.0	8.15
0.3	3.75	0.3								
0.4	5.0	0.4	5.3	9.2	6.2	8.8	6.05	9.3	6.35	8.55
0.5	6.25	0.5								
0.6	7.5	0.6	3.5	9.65	6.1	9.0	5.4	9.6	6.1	8.8
0.7	8.75	0.7								
0.8	10.	0.8	2.9	9.9	5.7	9.2	3.4	9.75	5.7	9.0
0.9	11.25	0.9								
1.0	12.5	1.0	2.7	10.1	5.4	9.4	2.9	9.95	5.3	9.15
1.2	15.0	1.2	2.6	10.35	5.15	9.55	2.8	10.2	4.9	9.3
1.4	17.5	1.4	2.5	10.6	4.7	9.7	2.6	10.4	3.9	9.3
1.6	20.0	1.6	2.4	10.7	3.9	9.85	2.4	10.6	3.05	9.65
1.8	22.5	1.8	2.3	10.8	3.15	10.05	2.4	10.8	2.75	9.8
2.0	25.0	2.0	2.2	10.9	2.8	10.2	2.4	10.9	2.5	10.0

Station Descriptions

Station 9 - Cattermole Creek (80/09/15)
- Parallel to South End of Dock
- Surface - Salinity 8 ppt
- 5 Metre Depth - Salinity 27 ppt

Station 10 - Mamquam Blind Channel (Mouth)
- Surface - Salinity 10 ppt
- 5 Metre Depth - Salinity 27 ppt

TABLE A-3 (CONTINUED)

RESULTS OF TITRATION OF 100 mL SAMPLES WITH

HNO_3 AND NaOH

Volume of 0.125 N Acid or Base	Equivalents ($\times 10^{-5}$)	% By Volume	Resultant pH Values with Base or Acid Addition							
			Station No. 11				Station No. 12			
			Surface		1.1 m Depth		Surface		5 m Depth	
			Acid Added	Base Added	Acid Added	Base Added	Acid Added	Base Added	Acid Added	Base Added
0.0	0.0	0.0	7.35	7.3	7.4	7.25	7.35	7.25	7.4	7.25
0.1	1.25	0.1								
0.2	2.5	0.2	6.95	8.6	7.4	8.3	7.05	8.3	7.15	8.2
0.3	3.75	0.3								
0.4	5.0	0.4	6.15	9.05	7.2	8.8	6.2	8.75	6.8	8.6
0.5	6.25	0.5								
0.6	7.5	0.6	5.4	9.3	6.0	9.1	6.0	8.95	6.5	8.8
0.7	8.75	0.7								
0.8	10.	0.8	4.9	9.5	5.65	9.2	5.6	9.2	6.1	9.0
0.9	11.25	0.9								
1.0	12.5	1.0	3.65	9.7	5.25	9.4	5.1	9.4	5.5	9.15
1.2	15.0	1.2	3.0	9.85	4.4	9.6	4.0	9.55	5.0	9.35
1.4	17.5	1.4	2.75	10.05	3.5	9.75	3.2	9.65	4.3	9.5
1.6	20.0	1.6	2.6	10.2	3.1	9.85		9.85	3.3	9.55
1.8	22.5	1.8	2.4	10.35	2.9	10.0	2.9	9.95	2.95	9.7
2.0	25.0	2.0	2.3	10.5	2.8	10.15	2.7	10.1	2.7	9.8

Station Descriptions

Station 11 - Mamquam Blind Channel, Opposite Last Piling
- Surface - Salinity - 14 ppt
- 1.1 Metre Depth - Salinity 19 ppt

Station 12 - Mamquam Blind Channel, South End Government Wharf
- Surface - Salinity 20 ppt
- 5 Metre Depth - Salinity 22.5 ppt

TABLE A-3 (CONTINUED)

RESULTS OF TITRATION OF 100 mL SAMPLES WITH HNO_3 AND NaOH

Volume of 0.125 N Acid or Base	Equivalents ($\times 10^{-5}$)	% By Volume	Resultant pH Values with Base or Acid Addition							
			Station No. 13				Station No. 14			
			Surface		3 m Depth		Surface		m Depth	
			Acid Added	Base Added	Acid Added	Base Added	Acid Added	Base Added	Acid Added	Base Added
0.0	0.0	0.0	7.3	7.25	7.3	7.2	7.3	7.2		
0.1	1.25	0.1								
0.2	2.5	0.2	7.2	8.4	7.1	8.15	7.1	8.6		
0.3	3.75	0.3								
0.4	5.0	0.4	7.1	9.15	6.7	8.5	6.9	8.85		
0.5	6.25	0.5								
0.6	7.5	0.6	6.8	9.4	6.3	8.8	6.8	9.0		
0.7	8.75	0.7								
0.8	10.	0.8	5.45	9.6	5.6	9.0	6.5	9.3		
0.9	11.25	0.9								
1.0	12.5	1.0	4.5	9.9	5.3	9.2	5.6	9.5		
1.2	15.0	1.2	3.5	10.1	4.7	9.3	5.3	9.6		
1.4	17.5	1.4	3.0	10.25	3.6	9.4	4.8	8.75		
1.6	20.0	1.6	2.8	10.45	3.1	9.5	3.8	9.85		
1.8	22.5	1.8	2.6		2.85	9.6	3.1	10.0		
2.0	25.0	2.0	2.5	10.6	2.7	9.7	2.9	10.1		

Station Descriptions

Station 13 - Mamquam Blind Channel, 100 Metre South of Railway Trestle
- Surface - Salinity 14 ppt
- 3 Metre Depth - Salinity 24 ppt

Station 14 - Mamquam Blind Channel, Above Highway Bridge
- Surface - Salinity 14 ppt